THE BOOK WAS DRENCHED

RAMBLING THROUGH SCIENCE

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BY

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CHAPTER I

About Locomotive Whistles and Other Things

DID you ever ride in a fast railroad train when another train passed you, going in the opposite direction, and the engineers, according to their habit, saluted each other by blowing their whistles? If so, did you notice that the whistle of the other train made two different sounds, one higher and one lower? Did you notice that you heard the higher note when the other train came toward you, and that, suddenly, this note changed to a lower one when the engine passed you?

If you have not already noticed it, keep this in mind and try it out on your next railroad ride.

Professor Rijke of Leiden noticed it, too, one day, but was not satisfied with merely noticing it; he wanted to know the reason why, and this is the explanation he gave for what is now known as Rijke's phenomenon:

Sound is just vibrations of the air. The vibrations are propagated in a wave-like fashion. If your ear catches so many waves per second, you hear a certain note; if it catches a different number, you hear another note. You say that the note is higher when you catch more of these vibrations in one second and lower if you catch less. Now, if a locomotive comes toward you while blowing its whistle, you catch more sound waves per second than when it is standing still or going away from you. This needs some further explanation.

Suppose you are standing on the sidewalk and a boy is coming toward you to give you a hand-bill. Really

not one boy, but a line of boys, so spaced that one reaches you every minute. If you stand there one hour (provided you are inclined to do so) you will collect sixty hand-bills.

If you should move toward the boys, and at a gait equal to theirs, you will meet the first boy half a minute after you start; and thus you will receive your first hand-bill in half a minute. The second boy is now just as far from you as the first one was when you started, and you will get your second hand-bill half a minute after the first. Keeping on in this way you will collect one hundred and twenty hand-bills, instead of sixty, in one hour.

Now suppose you had walked in the opposite direction; that is, in the same direction the boys are going, but at only half their rate of speed. Then the first boy will catch up with you in two minutes instead of one. The same will be the case with the second and the third boy and all the rest. In this way you will collect only thirty hand-bills per hour.

It makes no difference whether the boys carry hand-bills or sound waves. You meet more boys in one hour when you are going toward them, than when you are standing still; and you will be overtaken by less boys when you are walking in the same direction as they are.

The whistle on the train which you are meeting produces the sound waves and sends them toward you. When you and that train go toward each other, you will catch more sound waves per second than when you are going away from each other. In other words, in the first instance you will hear a higher note than in the second.

Let us philosophize a little bit about this phenomenon, and see if it may not lead to some interesting situations.

In the illustration, Fig. 1, you see a double railroad track with a locomotive on each track. You may not recognize the locomotives, but that is what the little squares are supposed to be. *A* and *B* are the engineers in their respective cabs. The locomotives go in the directions as indicated by the arrows. At the point where they ultimately meet, Mr. *C* stands alongside the track. About a mile farther is Mr. *D*, and somewhere on the track Messrs. *E* and *F* are standing.

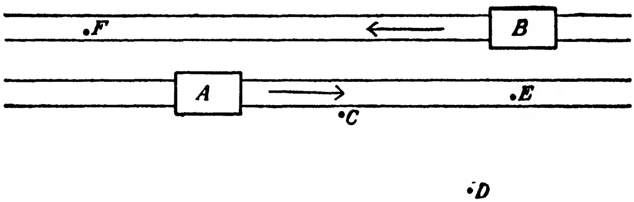


FIG. 1.

All the players being now in position, let us watch the action of the play:

When the two engines are about to pass each other, the engineers blow their whistles; and that is all there is to the play. But see what a difference of opinion there may be about such a simple act. All the gentlemen mentioned before happen to meet each other shortly after, and this is part of their conversation:

Says Mr. *A* to Mr. *B*, "You have a queer whistle on your engine. You blew first *a* and then *f*."

Mr. *B* says, "Nothing of the kind. *You* blew first *a* and then *f*. I blew *g* all the time."

Mr. *C* chimes in here (*C* is the man standing along the track), "Gentlemen, you are both wrong; both of you first blew *g* sharp and then *f* sharp. There was neither an *a* nor an *f* about it, nor was there a *g*."

Mr. *D* chimes in, saying, "It is surprising what strange things people can imagine. You three fellows

were close to that sound, and yet you don't know what you heard. Now I was a mile away from where you passed each other, but I heard you very plainly. Both of you blew *g* all the time, and there was no such thing as a queer whistle."

Mr. *E* then says, "You are right, Mr. *D*, there was nothing queer about the whistle, but you are wrong as to the note they blew. It was this way: Mr. *A* blew *g* sharp, and Mr. *B* blew *f* sharp."

Mr. *F* joins the conversation: "It was just the other way, Mr. *E*, just the other way; Mr. *B* blew *g* sharp and Mr. *A* blew *f* sharp."

And now *I* say, each of these gentlemen was right. Mind, it is not a matter of opinion, such as people may have about the color of things. One may say that a thing is mostly green and another that it is mostly blue, simply because that is the way it strikes them. I have taken great care to select my men. All of them have finely adjusted musical ears. Besides, I might have given each of them an instrument to register the number of vibrations received per second, and these instruments would have shown the same discrepancies.

I can almost hear you say, "I can see that these men heard different things, but what was the real note the whistle made?" Let us find out and put the instrument in the whistle, or at least very near to it. It says *g*. It says so whether the engine is running or not. All the men hear the same thing, provided they, as well as the engine, are standing still or going with it; but as soon as there is a relative movement between whistle and man, between transmitter and receiver, there is a different note, a different phenomenon. It makes no difference whether the engine stands still and the man or the instrument moves, or whether the man stands still and the whistle moves, or even if both move, provided, in this latter case, that they do not

move in the same direction and at the same speed. It is the relative movement that counts. However, I have not answered your question in a straight-forward way. I have set a certain condition before I answered: I said that the man or instrument must be in, or near, the whistle; in other words, that, if they move, they must move together. You asked what the real note was, and I'll be honest this time and answer that I don't know. I can only tell you what we observe, and we cannot observe unless there is an observer, be it either a man or an instrument.

Let us make another experiment. We will let the engine stand still, but whistle just as loudly as ever, and we will put a snail on the track. Would this snail hear a difference according to whether it crawls toward the engine, away from it, or is standing still? I cannot answer for the snail, and I'm afraid that, if we should give it the finest instruments ever designed, they would not be fine enough to record such infinitely small differences as would result from the slow pace of the animal. Besides, a snail is a rather far-fetched example, but you will see that it will come in handy later on in this book.

Now let us have a man walk on the track. It is just possible that some instruments might record it this time, but it is almost certain that the man himself could not hear the difference. A galloping horse might, though I presume that the horse itself would not pay attention to it, and wouldn't care about it if it did. A man sitting in an automobile running alongside of the track would certainly hear it, and an aviator flying at three hundred miles an hour over the track would hear an enormous difference. But—and this is the main point—there is a difference, be it large or small, so long as there is a relative motion between transmitter and receiver.

There was a time when the scientist used to say, "This is such, and that is so." But nowadays we do not make such positive statements. Now we say, "If the observer is in such and such circumstances or conditions, he will observe so and so." Let me give another example:

There is a man somewhere on a star, which is so far from us that it takes four years before its light reaches the earth. I have taken the necessary measures to have the clock of this man register the same hour as mine, and his calendar is exactly what mine is. When my calendar says June sixth, 1929, his says the same thing. On the fourth of March, 1929, I got a radio message from this man saying, "I notice with great pleasure that your Mr. Harding is being inaugurated as President. It is a very fine show I am seeing in Washington." I got this message by radio and I answered immediately. "You are all wrong. You're eight years off. Mr. Harding was inaugurated eight years ago and not today." Eight years later I receive a second message saying, "Perfectly true. When I got your message it was eight years since Mr. Harding was inaugurated. But why did you wait so long to answer me?"

Here again is a case where two men say different things about the same event and where both are right.

Did you ever stand in the street watching a company of soldiers marching behind a fife and drum corps? Did you notice that the soldiers were not in step? When your position was just opposite the last man of the company, this last man seemed to march properly but all the rest of the company were wrong? And did you notice that those in front were the worst sinners? In fact, that even the men of the drum corps were out of time with their own instruments, and that the amount of error was gradually getting less from the front of the column to the rear?

Now suppose, a little later, you meet one of your friends who was standing somewhere else on the street, his position being just opposite the drum corps itself. You discuss the poor manner in which those soldiers marched, and you tell him that the last man was all right but all the rest were wrong. He will answer immediately, that it is true that the soldiers marched poorly, but that your power of observation leaves much to be desired. For it was the drum corps which was in step and all the rest were more or less wrong, and the last man of the column was the worst sinner of them all. And again I say, both of you are right.

The explanation is a very easy one in this case. It takes some time before the sound of the drum corps reaches you and the last man of the column, but it takes, practically speaking, no time at all for you to see what happened at the head as well as at the tail end of the column. The last man heard the music at the time you heard it, and you saw him also at that time. Therefore you noticed that he was in step with what he and you heard. But you saw the first man before you heard the music to which he marched. Your friend observed under the opposite conditions. He saw and heard the drum corps at the same moment, and he saw the last man of the column just as quickly, which was considerable time before this man had heard the music to which he was marching.

In the case of the locomotive whistle, there was a difference of observations on account of relative speed, and in this case there is a difference on account of relative position. We ought to keep these two things in mind for future reference.

CHAPTER II

About Spiders and the Fourth Dimension

I AM telling you that there is a spider in the next room. You ask me where. I say that it is hanging three feet from the ceiling. You tell me that that is not enough to locate it, and so I add that it is four feet away from the wall where the closet is. You are not satisfied yet. You want to know more. So I tell you that it is seven feet from the wall where the window is. This ought to give you all the information you need, and so you go into that room and you come back and say that there is no spider, either at the point indicated by me or at any other point. "Well," I say, "it was there yesterday." You reply, "You should have told me that yesterday; then I could have seen it. It takes four dimensions to locate a thing, and you gave me only three." You are quite right. I should have given you three dimensions for the *where*, and one for the *when*.

Someone may object that these are not dimensions—they are distances and time. However, the word dimension is used in various ways. Ordinarily we think of dimensions as length and thickness and width. Dimensions give the size of a thing. But the word dimension is also used in another sense. It is used to give the location of an object or a phenomenon, and when used in that sense one, or two, or three dimensions are required to locate a point. If, for instance, we want to indicate the position of a certain station on the railroad line, we say that it is seven miles from *A* on the track between *A* and *B*. One dimension is sufficient here.

If, on the other hand, we want to indicate the position of a tree in a certain meadow, we can say that it is fifty feet from the rail fence and two hundred feet from the ditch which crosses that fence. Two dimensions are sufficient in this case. But in the case of the spider, three dimensions were required to locate its position in the room.

This room I imagine to be just an ordinary room with four walls, a straight ceiling, and of the common, rectangular shape. The various dimensions I gave you were all supposed to be at right angles to walls and ceiling, but it was not absolutely necessary that it should be so. I might have a room where the walls do not strike each other at right angles, and which might have had a curved ceiling; and I might not have had in mind dimensions at right angles to some of the walls. But so long as I give you the necessary information as to how I imagine the distances to run, you can locate the object. All I need is, what the scientists call, "three planes of *reference*."

Suppose the spider is hanging in a large ball, large enough to give you plenty of elbow room when you are inside, and suppose I ask you to indicate to me where this spider is. Your task has become a difficult one, for there is no plane of reference; there is not even a landmark from which you can start; there is nothing but yourself and the spider. You might stand up, face the spider, and report to me that the animal is three feet above your head, five feet in front of you, and six feet to the left of your left hand, but when you invite me to go in and see for myself I'll be at a complete loss, because I don't know what way you were standing. You have made for yourself a set of planes of reference, but that does not help me. It is not *my* set.

The thing to do is to build a platform in the ball, draw two lines on it at right angles to each other, and

give me the three dimensions, measuring from the floor and the two lines.

We have such a ball and such a platform. The ball is the universe and the platform is our earth, and for all who live on it three dimensions can be given without danger that some of us will think one thing and some another; but if there is another earth somewhere, we must not think that our dimensions are correct for their platform.

However, if we should happen to know the exact location and position of their platform, we might develop a formula which would enable them to translate our set of dimensions to fit the conditions of their platform and vice versa.

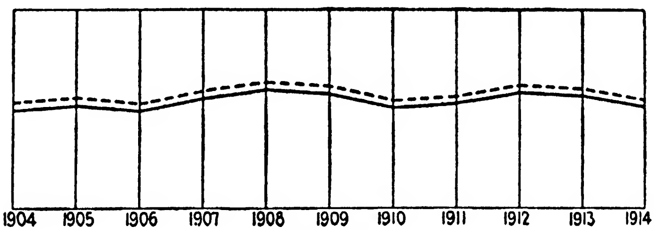


FIG. 2.

My friend on that far away star and I have agreed to observe the amount of rainfall over there. It is true that I don't see the rain at the moment it falls, but four years later, however, I can observe the amount as well as he can. Both of us plot the results and make what we call a graph. The vertical lines represent the amount of rainfall and the horizontal distances each represent one year. See Fig. 2.

Later we compare these graphs, which cover the same period, say from 1904 to 1914. The lower curve is mine, the upper one was made by my astral friend. You will find that my graph shows lower values than

his, and yet, I know that he is a very careful observer. Furthermore, both of us know that I see what happened on his star four years after he sees it, and we have agreed that I shall plot what I see in 1908 as having occurred in 1904. I must come to the conclusion that, after all, his year is not the same as mine, but a little longer. I ask my friend on the star about it and he tells me that the case is just the other way, that my year is a little longer than his. This sets me thinking, and I remember that the star does not stand still, but moves away from us with a speed of three hundred miles a second, so that the time for a signal to reach us becomes a little longer every year.

However, this is not all of the confusion. I am looking at the star through my telescope, which is very nicely adjusted to the proper direction. I have various data which enable me to calculate the distance this star is from the earth; but when I have done all this I get the wrong answer, for I forgot that the star is not there any more. It was there four years ago but now it is quite some distance further. That star travels three hundred miles per second, and there are more than one hundred and twenty million seconds in the four years that it took the light from that star to reach me. If it had been traveling, not away from me, but at right angles to my line of vision, I would not even be looking in the right direction.

This is what we have now: we get the wrong idea about direction, about distance, and about time unless we take certain things into consideration—things which are not apparent on the surface. What the whole thing comes to is this, that we cannot make proper observations simply by considering the phenomenon we are trying to study, but we must also and at the same time consider the relation between observer and event.

The worst of it is that time and place are interwoven. My time and that of the man on the star are not the same, and the difference depends on our relative motion. If only both of us were standing still, or if both of us were moving in the same direction and with the same speed, it would be easy to come to an agreement as to what is taking place here and there; but we are not. We are going in different directions and at different speeds; and, quoting the old song, every little movement has a meaning all its own.

We can define most things by referring to some other thing which is simpler, or which has a broader meaning. For instance, we can define a chair as some kind of seat, but there are some conceptions which are so simple or so broad, which are so much part and parcel of our consciousness, that it is not possible for us to think of anything simpler or broader to which we can refer. Time and space are such conceptions. Space just is, and so is time; not only that, but it is not possible for us to picture in our mind limits of either space or time. We cannot think of a beginning or an end of time, nor can we think of space as being limited or unlimited.

One of the most difficult things to do is to realize our limitations; not our personal limitations, but those of the human mind in general. However, the fact that we are unable to picture a thing should not make us think that it cannot exist. If our limitations do not allow us to form a picture of something about which we wish to learn the truth, we should set our mind to work and try to learn that truth by some other than the pictorial method. Perhaps the best of all tools to employ for such a purpose is mathematics. People may have widely different opinions about color, or sound, or taste, or smell, and yet consider each other perfectly sane; but difference as to a mathematical truth can

only be due to ignorance or insanity. We are so used to depending on mathematics in our daily life that we no longer realize it. We depend on it when our property is surveyed, when a bridge is built, when a tunnel is driven, when machinery of all descriptions is constructed, and we take the results for granted, even though we ourselves are not able to carry out the calculations needed for the task at hand.

When we wish to arrive at some truth by means of mathematics, we must be sure of the elements on which our calculation is to be based; and if we then arrive at some result which seems to be at variance with our previous knowledge or conceptions, we must come to the conclusion, either that the elements used were not correct, or else that our previous knowledge of the phenomenon under investigation was faulty.

In recent times mathematical investigations have brought forward a number of conceptions which are foreign to our accustomed way of thinking and some of which do not permit us to form a mental picture of them. However, we must not forget that, even among the conceptions with which we are perfectly familiar, there are a great many of which we cannot possibly form a mental image. Who, for instance, can have a correct mental picture of a million cows? And yet nobody thinks that they cannot exist. Among the things of which we cannot form a mental picture is the fourth dimension, and this is mainly so because, when we think of dimensions, we think of length and breadth and thickness of an object; and, true, as such there cannot be more than three; but as indicators which locate and define a phenomenon or event they can exist in any number. In the relativity theory the fourth dimension is probably the bogey man which has scared most people and prevented them from making themselves acquainted with this epoch-making theory;

and yet, in the previous pages, the fourth dimension was mentioned as an everyday affair; only there it was introduced as the fourth necessary ingredient of the *where and when.*

Simply because we are not able to see or hear a thing the moment it happens, we get a distorted picture of reality. We do not see the stars where they are, but where they were some time ago; and if it took the same amount of time for the light of all stars to reach us, we would still see them in their proper relative position. But the light from one star reaches us in one year, that from another in ten, and from still another in, perhaps, ten thousand years; so that, not only do we not see them where they are at the moment we observe them, but we do not even see them in their proper relative positions.

If we should make a map of the skies and give it to an inhabitant of some other star, he would tell us that our map is not correct and we would say the same about the map he had prepared. If we are sufficiently broad-minded, we will come to the conclusion that our map is all right from our standpoint and his map from his point of view, but that there must be a difference between the two maps, not because mistakes of observation had been made, but because there is a difference in the conditions of the two observers. Each map is correct, relative to the planes of reference chosen; but the two sets of planes were not the same.

It was thought for a long, long time that light reaches us instantaneously, because, with the crude measuring instruments at hand, no such enormous speeds as the speed of light could be measured. With refinement of instruments and methods it became possible to measure this speed with a high degree of accuracy, and it was found to be three hundred million meters, or one hundred and eighty-six thousand miles

per second. The fact that the light from the nearest fixed star takes almost four years, and from some other stars a hundred thousand years, gives us an idea, but not a picture, of the enormous distances in our universe. That light is not instantaneous but has a definite speed is the cause of our seeing things that were, but not the things that are. It compels us, if we wish to be correct, to say that things, as observed, are thus and so in relation to our viewpoint; or, saying it more scientifically, in relation to our planes of reference. It also compels us to introduce the fourth dimension, and it takes away the nice assurance we once had, that we could know exactly when and where a phenomenon or incident took place; for, whatever way we try to describe such an incident, we find that space (location) and time are hopelessly tangled up so that neither of the two can be used by itself.

The principles of the much discussed theory of relativity are just these: that all observations must be considered in relation to some definite set of planes of reference; that it is not possible to say that things are thus or so, but that we must say that they are relative to our one given set of conditions. These principles are easy to understand; but when we try to correct the observed data so as to make them correspond to the conditions of some other set of planes of reference, for instance for the inhabitants of some far away star, we run up against some very difficult mathematics; and when we apply these mathematics, we reach conclusions which are very difficult, if not impossible, to picture. However, we know that, if our data are correct, and we have made no mistake in our mathematical work (and that can be made absolutely sure of), then we must accept the result as true, whether we can picture it or not.

In all of this the speed of light plays the main role.

CHAPTER III

Light Literature

LIGHT travels with a speed of 186,000 miles per second. This is such an enormous speed, so far beyond any of the speeds with which we are familiar, that it is quite natural to hear someone say, "I'd like to see you measure it." It does seem to be a hopeless task to measure such speed, and especially to do it with such a degree of accuracy that we can use it as the basis for further investigations and calculations and

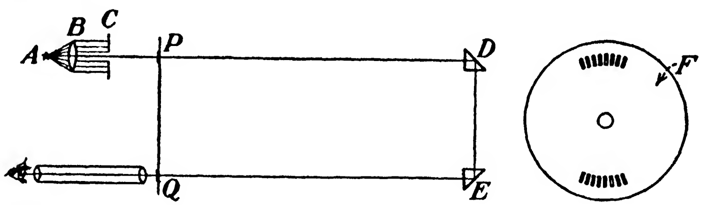


FIG. 3.

theories. Nevertheless, it has been done by different men and along different ways and with a wonderful degree of accuracy. Figure 3 is a diagram of the principle of one of the methods employed. In reality other details were used, but the principle being the same I feel at liberty to modify the details in order to get a somewhat simpler diagram.

A source of light *A* is made to project a parallel beam by being placed at the focal point of a lens *B*. Part of the light is intercepted by a diaphragm *C* and the remainder proceeds to a prism *D* where it is reflected to another prism *E*, then reflected once more, and this time in a direction parallel to its original direction so

that it can be observed through a telescope. A large wheel *F* is interposed in the path of the light in such a way that it intercepts the light both going and coming. In this wheel there are a large number of very narrow slots and at the start the wheel is so adjusted that the beam of light passes through one of the slots on its outward journey, and through another slot, exactly opposite the first one, on its return. So long as the wheel stands still, the beam of light can pass through both slots and can be seen through the telescope, but as soon as the wheel moves with sufficient speed something else takes place. During the time required for the light to pass from the upper slot through the distance *PD-DE-EQ*, the slot *Q* has moved and the beam of light strikes a space between the slots instead of the slot itself. If now we keep increasing the speed, we shall finally reach such a speed that the returning light passes through a slot, but not the one directly opposite the one through which it passed on its outward journey. All we have to do then is to start the wheel and increase its speed until no light is observed through the telescope and then keep on increasing until the light is seen again. If the distance which the light must travel between *P* and *Q* is ten miles, and if there are 500 slots in the wheel, and if we find that we can see the light again when the wheel turns at a speed of 2232 revolutions a minute, then we can calculate that this light had a speed of 186,000 miles a second. The calculation is a simple one: When we skip one slot we skip one five-hundredth part of the circumference of the wheel. The wheel makes a whole turn in 1/2232th part of a minute, so that the space between the two slots is passed in 1/2232 × 500th of a minute; and in that time the light must travel ten miles. The speed of light is therefore 500 × 2232 × 10 miles a minute, which figures out to be 186,000 miles a second.

Lately the speed of light has been redetermined by Professor Michelson and with a surprising degree of accuracy. His method was the same as described here (except as to the details). Instead of the revolving wheel with the large number of slots, he used a revolving octagonal mirror. Many precautions were taken to avoid various sources of error and the experiment was repeated a number of times. It might reasonably be expected that the results obtained from these repeated observations would differ to a certain small extent. If someone weighs off a number of quantities of material, each a hundred pounds, and it is later found that these quantities differ by not so much as one ounce, we will certainly come to the conclusion that some very accurate weighing has been done. Now here are the results of five of these experiments or determinations by Michelson:

299,797 km. per second
299,795 km. per second
299,796 km. per second
299,796 km. per second
299,796 km. per second

A difference of one ounce in a hundred pounds is a difference of one in sixteen hundred. The differences found in the results of Michelson's experiments have a maximum of two in about 300,000 or one in 150,000.

The question of what is light has puzzled the world a good many years, and is not definitely settled yet. Science has a way of keeping the scientist busy with corrections of old and cherished theories; and the true scientist loses neither sleep nor courage when he finds that what he once thought to be the ultimate truth is only an approximation, or perhaps a fallacy. Science has only one aim: to find the truth, or at least to come as near to it as circumstances will allow. Dogma and science are direct opposites. Dogma says, "This is the

final truth," while science merely claims, "Such and so is the present state of our knowledge, and we are ready to change our ideas and theories as soon as we find new testimony."

One of the oldest theories about the nature of light, and one which found a great many followers, was originated by the famous scientist Newton. He suggested that light was a bombardment by a large number of infinitely small bodies, corpuscles he named them, sent out by the light-giving body. Reflection was merely the rebound of these small bodies, in much the same way that a rubber ball rebounds when thrown against a wall. He had an ingenious explanation for other phenomena, such as refraction, and for that particular phenomenon he assumed that the speed of light was greater in heavy or dense bodies than in lighter or less dense ones. This happens to be the case with sound. You can easily try this out for yourself. Put your ear to a waterpipe. Let somebody strike this pipe a smart blow. Of course, there must be quite some distance between you two, or else the time between the striking of the blow and the moment that you hear it is too short to make any correct observation at all. However, if the distance is sufficiently great you will hear three sounds. First you hear the blow as the sound comes through the iron pipe, then as it comes through the water in the pipe, and finally as it comes through the air.

The case is just the opposite with light. It travels fastest through a vacuum and slower as the medium through which it travels is denser. This was found later and was one of the reasons why Newton's theory was dropped.

Newton's contemporary, Huygens, took another view of the matter. He assumed that light was a wave motion, very much like sound and yet different. You

can get a very close idea of what the wave motion of sound is like in this manner: Take a length of rope and tie one end to the bedpost or anything else you like, and hold the other end in your hand. Give your hand a quick short shake and see what the rope does. You will find that the jerk of your hand has caused a wave to form in the rope and that this wave travels from your hand to the other end of the rope and, if the rope is of the proper length, back again to your hand.

This is the kind of thing which takes place in an organ pipe, where the air in the pipe does what your rope did. There are also other kinds of vibrations which make what we call sound. You can best observe them by watching a taut violin string. Whereas the first kind of waves traveled lengthwise of the rope or the column of air, the vibrations of the violin string traveled crosswise. However, Huygens did not assume that light waves were similar to either of these two kinds of sound waves, but that they were of an entirely different nature. It is somewhat difficult to form a correct picture in one's mind of just what such waves look like. Perhaps the best thing to do is to compare them to something with which one is familiar and then remember that, after all, this is only by way of illustration and not the reality. Just imagine, for example, a number of rubber balloons, such as children play with, all deflated and all connected by a rubber tube. Then imagine that someone inflates the first one, but without affecting the others. Then you press this one with your hand so as to deflate it and, in some way, you shift the air from this balloon to the next. Then you deflate the second one and force the air into the third one, and so on. In this manner you get a succession of balloon-like waves. However, you must keep in mind that this is only an imperfect illustration and not the real thing.

Huygens explained with his wave theory all of the then-known phenomena of light. Each of the two scientists, Newton and Huygens, had his followers and for a long time the scientific world was divided into two camps, with now the one party and then the other the stronger. However, in the beginning of the nineteenth century some new phenomena were discovered which could not be explained at all by the theory of Newton, and from that time on until now the Huygens wave theory has been accepted as the one possible theory.

When I said that new phenomena were discovered, I did not mean that they had never been seen before; but that, if seen, nobody had paid enough attention to them to try to explain them, or even to notice that they were unexplained by the then existing knowledge. Such things often happen; in fact, it may be said that it is the regular thing. The difference between the scientist and the casual observer is, that the first one tries to connect the newly obtained fact to something he already knows, while the other stows it away in his memory as an isolated fact, or else forgets it.

The Englishman, Young, and the Frenchman, Fresnel, noticed the phenomenon of the interference of light, and explained it on the basis of the wave theory, while it was entirely impossible to explain it on the basis of the corpuscular theory of Newton. You ask, "And what is this interference of light?" and I'll have to ask you to wait a little while because I'll have to talk about a few other things before I come to it.

About the middle of the nineteenth century Clerk Maxwell found by mathematical calculations that light is an electromagnetic phenomenon, and several years later Hertz came to the same conclusion by the experimental method; and, such is science, that now we are not quite certain about anything. The Ger-

man, Planck, threw a bomb into our nicely arranged knowledge when he proposed his quantum theory. We still believe that light is a wave motion and that it is of electromagnetic origin, but we are coming back to a somewhat modified corpuscular theory as well.

The last two paragraphs do not explain anything; they are just history.

CHAPTER IV

Ethereal Things

HUYGENS realized, as we all must, that there can be no wave motion unless there is some substance subject to that motion. However, light seemed to come across the empty spaces of the universe, and it was unthinkable that there should be a wave motion where there was nothing to wave. He therefore assumed that, after all, there must be some kind of substance in what seems to be empty space, and that this substance is of such a nature that it cannot be observed as such, but only by the forces it conveys. This substance was called the luminiferous ether.

Huygens was not the only one to think so; in fact, everyone including Newton asserted that there was such a substance, if substance we can call it. Newton really did not need it to explain the fact that light came through empty space, for a brick needs no material to carry it when it is thrown from one place to another, and neither does a corpuscle. However, he ran into some difficulties when he tried to explain the phenomenon of reflection, for such an infinitesimal thing as he supposed the corpuscle to be would probably slip in between the particles of which the reflecting body is composed, and so he suggested the idea that all space, including that between the molecules of a body, was filled by the ether, but that this ether was of different densities and was densest in empty space, and more and more attenuated as the material which is pervaded was heavier or denser. At the boundary of the material there was supposed to be a

layer of decreasing density and the stream of corpuscles was supposed to undergo a gradual bending so that finally it would be completely turned around and so give the impression that it had been bodily thrown back. I wonder if he got the idea from the contemplation of a mirage, which as we know is caused by the light passing through layers of air which are of different densities due to the heated condition of the ground.

In the course of time this ether has undergone many changes in the minds of scientists. It has been so very attenuated that there is nothing on this earth with which to compare it, and so light that it had really no weight at all and was therefore called the imponderable ether. Then again, it was supposed to be very heavy and a thousand times more rigid than steel. In either case it was supposed to be perfectly elastic; that is, it would come back to its original condition as soon as the force which had disturbed it would cease to work, and it would not absorb any of the energy which had distorted it—which is merely another way of saying that it was perfectly elastic. Some thought that the ether was perfectly homogeneous, or rather, continuous; in other words, that it was not composed of separate particles such as we know our earthly materials to be, and others speak of the *structure* of the ether, which means exactly the opposite. All agreed, however, that there must be an ether, until Einstein developed a theory which ignores the ether completely.

What the various scientists really wanted to express was that there was something which made it possible to carry forces or waves or vibrations through space, which, so far as they could ascertain, was perfectly empty. The human mind is such that we cannot imagine action at a distance. Another one of our limitations. It is, after all, much easier to say that such and so is transmitted by the ether than to say, "It is

transmitted in some way but we don't know how, or by something but we don't know by what."

It is perhaps best not to think too much about this ether, for if one does one is likely to land in the midst of a lot of contradictions, which is merely another way of saying that the whole thing is a muddle. Just as an instance: if the ether has a structure—that is, if it is composed of separate particles—how does the wave, or vibration, or force get from one particle to another if action through a distance is not possible? And again, if it is homogeneous how can there be waves? And so, as I said before, the best thing to do is not to worry about the thing at all, but to enjoy the remarkable results of the theories which were based on this elusive material.

Notwithstanding the excellent piece of advice I presented you with in the preceding paragraph, I am compelled to come right back to the selfsame ether. One of the questions raised was this: if there is an ether, does it go with us as we sail through space, or does it stand still and are we sailing through it? In the latter case there should be something to show us that we do. Michelson (the same one who determined the speed of light with such astounding accuracy) and Morley carried out some experiments which are remarkable, not only on account of the ingenuity displayed, but also, and especially, because the result has been the foundation for much new thought.

You remember the locomotive whistle? As it approached you the sound was of a higher pitch than it seemed to the engineer in the cab, and as it was going away from you, that same sound seemed lower. Keeping this in mind, and remembering that light is a wave motion, the two experimenters reasoned that, if you measured the speed of light as you were going toward its source, you should get a higher value than if you

were going in the opposite direction or than if you were going in a direction at right angles to the beam of light. This sounds reasonably easy. All you have to do is to measure the speed of light under these two conditions. However, if you consider that it takes a few years to do such measuring with some degree of accuracy and that you, with the earth, are describing a curved and not a straight line, you will come to the conclusion that it is not so easy as it looks. If your source of light is that of a star you will have to remember that you are constantly shifting your direction. And, besides, what is the star doing meanwhile? And then there is still something else. A snail on the track where a locomotive is standing would hear no difference of pitch, whether it was standing still or going to or from the locomotive. Its speed is too slow as compared with that of sound.

Well, a snail on the track is not so much slower as compared to the speed of sound waves than we are as compared to the speed of light. We are sailing through space at the rate of about nineteen miles per second, a speed which would bring you from New York to San Francisco in two and a half minutes, but as compared to the speed of light, which would whirl you almost eight times around this earth in one second, we are really not fast at all. Whatever difference we would find would be but a small percentage of the total; in fact, it would be only one hundredth of one per cent.

However, this smallness of the possible result did not prevent the two gentlemen from having a try at it. As you have seen, Michelson was able to make his experiments with a very much smaller probable error than one hundredth of one per cent. On the other hand, they realized that the constant change of direction, as the earth circled around the sun, would not permit them to measure the light coming from a

star, first when it was going toward it, and then as they receded from it. A more or less indirect way would have to be used. They made use of the interference of light. I mentioned this interference once before, and I feel that it is about time to say more about it before I tell how Michelson and Morley used this phenomenon to determine whether we were sailing through the ether or whether the ether was going along with us.

You have noticed, of course, how a stone, thrown into a quiet pond, starts a set of ripples. At a first glance it seems as if some of the water travels from the center out and meanwhile goes up and down. However, a little experiment will show you that this is not so. If you had placed a piece of wood somewhere on the water, you would have seen that this piece travels only up and down, but that it keeps its position relative to the shore. The particles of water vibrate vertically. Now suppose your friend throws another pebble somewhere else in the same pond. He also starts a set of ripples. Gradually these two sets of ripples approach each other, and let us suppose that you two have timed your pebbles so that, as the two sets meet, your ripple is going up and your friend's is going down. The result is that at that particular moment there is no movement of the water. It goes neither up nor down. This is interference of ripples, and something similar happens when there is interference of light. Before going further with this, I want to call your attention to an experiment about the interference of sound, an experiment which you yourself can carry out without much trouble.

Take some wooden box, say a cigar box, and place a tuning fork on top. Bore a couple of small holes in the side of the box and attach there two small rubber tubes. The other ends of these tubes should be attached to a forked ear piece, so that the sound of the tuning

fork will reach you through both tubes. If you detach either one of the tubes you will hear the sound as well as when both were attached. Now detach one of the tubes at one end and cut a small piece off. Then attach again and try once more if you can hear the sound of the fork. You probably will, but if you keep on reducing the length of one of the tubes by small amounts, you will soon come to a point where you can hear the sound of the fork through either of the two tubes but not when both tubes are attached to the ear piece. The reason is that the sound waves have entered the tubes simultaneously at the box end, but when they came to the ear end there was a difference of phase, meaning, that while the wave in the one tube was swelling, the wave in the other tube was contracting. One wave was counteracting the effect of the other.

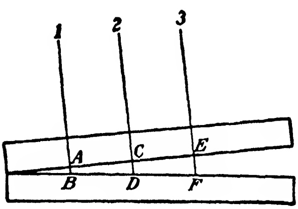


FIG. 4.

Now, although light waves are of a different nature, they too have what may be considered as swellings and contractions; and, if we can arrange it so that a swelling shall coincide with a contraction at some point, then we shall have no light there.

Figure 4 shows a simple arrangement by which we can produce this effect. You see there two pieces of glass, laid so that there is a small angle between them, a much smaller angle than could conveniently be shown in the drawing. A beam of monochromatic light (say yellow light, such as you get when you throw some table salt or soda in the flame of a spirit lamp), is used to illuminate the pieces of glass. The drawing shows the path of some of the rays of that light.

Three rays of light are shown in the drawing. Ray 1 reaches the bottom of the top piece of glass. Part of the

light is reflected there, and another part goes on and is reflected at *B*. Now suppose the distance between *A* and *B* is exactly one-fourth of the wave length of this kind of light, then double this distance is exactly one-half of this length; and therefore, the light returning from *B* is precisely one-half of a wave length behind that part of the light which was reflected at *A*. The two ripples interfere with one another, and at that point there is darkness. Ray 2 is shown at a point where the distance between *C* and *D* is exactly one-half of a wave length; so that here the light returning from *D* is just a whole length behind that returning from *C*. As a consequence, these two impulses help each other, and we see bright light at that point.

Ray 3 is chosen where the distance between *E* and *F* is three-fourths of a wave length; so that the light returning from *F* is one and a half lengths behind that coming back from *E*. At that point, then, there is again interference, and this will happen so long as double the path between the two pieces of glass is an odd number of half wave lengths. Of course, the reflecting surfaces of the two pieces of glass must be very flat. If they are not, then the light will be reflected hither and yon, and no definite phenomenon takes place at all.

It is rather interesting to know how such absolute flatness can be assured. This is the way it is done:

Three pieces of reasonably flat glass are chosen to begin with. Two of them are rubbed together with some abrasive between them. They are rubbed until they fit each other, that is, until there is no space between them. One can try this out in a very simple manner. Placing the one piece on the other, and illuminating them with a monochromatic beam of light, as we did in our previous experiment, we should not see light and dark bands or rings unless there is a space somewhere between the two pieces.

However, when we find that the two pieces fit each other perfectly, this is no proof that they are flat, because one of them might be concave and the other convex. We have rubbed pieces *A* and *B* together, and now we will rub pieces *A* and *C* until they fit each other. Now suppose that piece *A* is concave; then it will have a tendency to make piece *C* convex. We have now two convex pieces, namely *B* and *C*. We will now rub these two pieces together and so reduce their convexity. Constantly changing the mating pieces in this manner we keep on reducing whatever error there may be until finally we see no interference bands whichever two of the three pieces we try together.

Experiments of this kind seem to be very far from our daily life; in other words, of no practical value, and yet our American system of economical mass manufacture depends, to some extent, on just this very phenomenon of the interference of light.

To be able to make a thousand pieces in one part of the factory and a thousand other parts in another department, and then to be sure that we can take any one of the first group and that it will fit any one of the second group, requires that each part be made to very accurate dimensions. In such factories the inch is no longer the unit of length; it is the one-thousandth part of an inch. The words "one-thousandth part of an inch" do not mean much to the average citizen, but this is a way to get some idea of what they mean: the thickness of a human hair averages two-thousandths of an inch, and there is really not much variation in size. A hair, two and one-quarter thousandths thick is unusually coarse; and one of a thickness of one and three-quarters is unusually fine.

Now, in many kinds of work the limit of accuracy is the tenth part of one-thousandth of an inch, or, what is the same, the twentieth part of the thickness of a human

hair. To be sure that the measuring instruments in the factory are correct, we must have still finer instruments for inspection. It would not do to weigh a pound of some material on scales which do not show differences of less than a pound. Similarly, we must have inspection instruments which will show errors of much less than one-thousandth of an inch, or of one-tenth of a thousandth. And, again to be sure of the accuracy of our inspection instruments, we must have something which indicates smaller errors than we can allow in these instruments, something which is absolute, which does not change and which does not wear, however long we use it. The marvelous thing which fills these requirements is the wave length of monochromatic light; and this thing is now internationally accepted as the standard of length.

They have in Washington a bar of metal which is the standard of length for the United States. It is made of an alloy of platinum and irridium and is kept at a constant temperature. It is our standard yard. Notwithstanding all possible precautions, there is no assurance that this bar will not change its length in the course of time. Metal has a way of changing which is sometimes very baffling. Besides, there is always the danger that someone might drop the thing, and then what would be a yard? The monochromatic light wave, however, is not subject to breakage, to expansion, contraction, or any of the other diseases to which a metal bar may be heir.

We now say that our standard yard has the length of so-and-so many waves of orange light. If, at any time, there should be doubt as to the correctness of the standard bar, it is possible to come to a conclusion by measuring again the length of the light wave. If we should find that there are 49,900 light waves to the inch as we find it on that bar and we had agreed that

the standard length of the inch should be 50,000 light waves, then we know our error and we are in a position to make the necessary corrections.

There are many other ways in which interference of light occurs, and we will probably come across some of them during our ramblings through science. However, now we must go back to our friends Michelson and Morley and see what they have been doing.

If we let a beam of light travel in the direction in which we are sailing through space, and another beam at right angles to that direction, and arrange things in such a way that, ultimately, these beams strike a screen at the same spot, and if there is really any difference in the speed with which these beams travel, then there is a chance that one beam might be half a wave length behind the other. I say there is a chance, but a chance only—no assurance. If now we turn our experimental apparatus slowly, we shall bring the first beam of light a little off the direction in which we are going, and the other beam a little more to that direction, and, continuing in this way, we shall finally reach a point where the difference in the times when the two beams reach the screen is just equal to one half the time for one wave, or else an odd multiple of that time.

A diagram of the apparatus used by the experimenters is shown in Fig. 5. *S* represents the source of light used in the experiment. *AB* is a piece of glass, one half of which is silvered. The light is directed in such a manner that part of it goes through the plain glass, while another part is reflected on the silvered surface. The first part travels on to the mirror *Q*, then back to the mirror *AB* and then on to the receiving instrument *I*. The going rays are indicated by the full lines, and the returning rays by the dotted lines. The other part of the light is reflected on the mirror *AB*, then goes to the mirror *P*, is again reflected,

and now goes on through the glass *AB* to the receiving instrument. If we move through the ether, then the speed of light in the direction *ABP* must be different from the speed in the direction *ABQ*; and, by turning the entire apparatus, we will observe the phenomenon

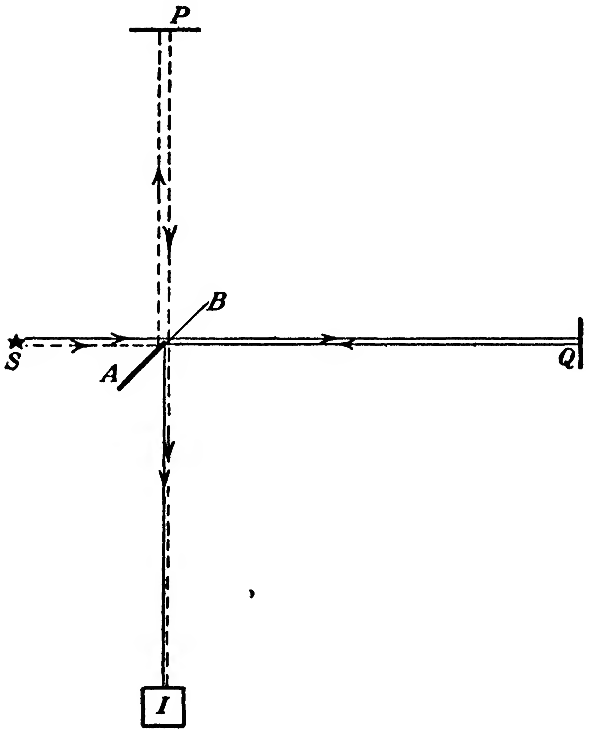


Fig. 5.

of interference. Someone may object that, if the light is speeded up when going in the direction *ABQ*, it must be equally slowed down on its return trip *QAB*, and that the one would neutralize the other, and such a remark would be near enough right to deserve an answer and an explanation.

If the line between *AB* and *P* represents a river, flowing at a rate of 4 miles an hour, and a boat is traveling on it which has a speed of 20 miles an hour in still water, and if the distance between *AB* and *P* is 24 miles, we can figure out how long this boat requires for a return trip, and we can also figure out how long it would take if there were no current in the river. In the first case, the boat would be traveling from *AB* to *P* at the rate of 24 miles an hour because it is helped by the current to the extent of 4 miles, and it would reach *P* in just one hour. However, going in the opposite direction it would be slowed down by the same amount of 4 miles per hour, so that its actual rate of travel would be 16 miles per hour, and therefore it would make the homeward trip in $1\frac{1}{2}$ hours; so that the entire trip takes $2\frac{1}{2}$ hours. Now, if there were no current, the boat would travel all the time at the rate of 20 miles per hour and the distance out and back would require $\frac{48}{20}$ hours, or 2.4 hours, which is not the same as we found by the assumption that there was current.

The actual apparatus was, of course, more elaborate. For instance, there were several mirrors to reflect the beams of light back and forth, so as to obtain a longer path for the light without making the apparatus too large. The entire structure was mounted on a table floating on a bath of mercury so as to be able to turn it gently without any danger of displacing one element in relation to another.

The experiment showed no difference of speed at all, so that we have to come to the conclusion that the ether goes with us, or else that there is no ether at all—or maybe some other conclusion.

CHAPTER V

How Tall Are You?

TO assume that the ether goes with us is equivalent to saying that our little earth is the center of things, and that the whole universe gyrates around it, and this is really too egotistical an idea for a modest person, and scientists are nothing if not modest. On the other hand, to assume that there is no ether at all, is coming back to the impossible situation that we must imagine action taking place at a distance, without any medium to carry the forces which cause the action. Fitzgerald suggested that the reason may be that it is not possible to measure correctly when we are in motion. He said that a two-foot rule is no longer two feet long when you move it in the direction of its length, and that the faster you move it the shorter it becomes.

Let us say that I am measuring your height while the earth and you and I are sailing through space in the direction of the line going from your head to your feet. The only way in which I can do this, is by holding the two-foot rule in the same direction; and, if our friend Fitzgerald is right, you have become somewhat shorter than you would be if the earth and you with it were standing still. But how am I to find this out? My measuring instrument has become shorter too, and in the same proportion, and so has every division on it. If I could make the earth stand still, I would find you to be five feet eight inches tall; and I find the same thing while the earth is moving. But somewhere, on a star which is moving at a right angle to our direction,

there is an observer who is also interested in your height, and who has the necessary instruments to measure you, though he is many millions of miles away. His measuring instruments are not shortened in the same direction that mine are, and so he measures you with a longer inch and tells you that you are not quite five feet eight; and so we have here again a case where different people say different things about the same thing, and where all are right; that is—if Mr. Fitzgerald was right. The whole idea of the dimensions of a thing changing, simply because it moves, is so strange that various scientists and philosophers have tried to put the idea in a form which would make it a little more acceptable.

Poincaré, the scientist (not the former premier of the French Republic), put it this way:

Suppose you were asleep, and in the meanwhile everything became a hundred times as large as it was when you went to bed, how would things look to you when you woke up in the morning? Mind, everything, and every dimension of everything, has become larger, you included. The answer is that everything looks just the same as it did the night before. It takes you again six steps to go from one end of the room to the other, because, though the room is now 1500 feet long, your legs have grown in proportion, and instead of taking steps of two and a half feet, you now take strides of 250 feet in length. You can still barely reach the switch of the overhead light. You have still the same feel when you grab your fountain pen, though it is a little over three feet in diameter. If the idea comes at all into your head that the pen is of unusual thickness, you take your trusty two foot rule and find that the pen has not changed at all. Everything has changed, and therefore nothing has changed; for—and this should be remembered—we can observe only by comparing

one thing with another. If everything in the world were red, there would be no such thing as color. And so you see that Fitzgerald made a statement which nobody ever will be able to disprove by actual experiment.

Lorentz of Leiden had the same idea, but he did not stop there. He studied, by mathematical analysis, what the effect of such a condition would be. You see, in science anybody is free to present his pet idea as to what may be the reason for this or that, and if it sounds as if there might possibly be something in it, other scientists will take it up and subject it to various tests in order to ascertain whether or not there is enough corroborative evidence to accept the idea as a working hypothesis. Before such an idea is admitted to the company of other hypotheses of good standing, it must fulfill three conditions: it must explain the phenomenon which it is supposed to explain, it must not run counter to established facts, and it must be able to predict the existence of some new facts. If these predicted phenomena are then found by experimental methods to exist, the idea is accepted on probation. When mathematics are applied to the new hypothesis, and it is found that measurements and numerical results correspond to the results which the mathematical treatment has predicted, then this hypothesis is promoted to the status of a theory. You see that the scientist uses the word theory in an entirely different sense from the average citizen, who has a wild idea about something and calls it his theory.

Taking for granted, for the time being at least, that the idea of Fitzgerald was correct, Lorentz calculated how much such a shortening of dimensions would have to be for a certain speed of an object and he established a formula for it. He also found that not

only was the length of a piece affected by its speed, but also its mass, and he established a formula for this too. Now, though it is not possible to find experimentally the change in dimensions, it is possible to find the change of mass, and this was actually done and the results of such actual measurements agreed fully with the Lorentz formula.

You must not imagine that it is possible to weigh a ton of bricks, load it on a railroad car and weigh it again while the train is in motion and that then you will find a different result. In the first place, your weights are also on that train and are affected by its speed to the same extent as the bricks; but—and this is even more serious—the speed of that train is like that of the now familiar snail on the track. There is no speed with which we are personally acquainted which is great enough to affect the mass of a body to a measurable degree. Nevertheless, the change of mass was observed and measured; but it was done, not with a load of bricks, but with little particles, so small that the finest chemical balance is entirely too gross to weigh them, and it was done while the particles had a speed far beyond anything we see in our daily life. It was done with electrons moving with a speed approaching that of light.

I have mentioned the word *mass* a few times, and you may think, as many do, that it is the same as weight, especially so, because I spoke of weighing the load of bricks in order to find if there was any change in the mass, and it begins to look as if I made a slip there. Mass and weight are closely allied but they are not the same. If I should weigh an object here with a spring balance and found it to be ten pounds, and if I then took the same object to the moon and weighed it with the same spring balance, I would find that it weighs very much less.

I'll have to confess to a weakness in some of my arguments so far. I have been referring you to some star, so far away that it takes its light four years to get here, knowing full well that you have no chance at all to go there and check me up; and now I am referring you to the moon, which is just about as hard to reach, Jules Verne to the contrary notwithstanding. However, this time I can refer you to some place which you can reach. If you will kindly take this ten-pound piece to the North Pole, or to the South Pole if you prefer it, you will find that your piece weighs more than ten pounds; provided that you weigh it with a spring balance and not with ordinary scales. If you use scales you will have to use weights; and these weights are also heavier there than here, and in the same proportion as the piece you are trying to weigh. It is not even necessary to go as far away as either of the poles. So long as you weigh your piece at different latitudes, you'll find a difference.

And why? For two reasons: in the first place, this earth is not a perfect sphere, but is gradually flattened toward the poles, so that with increasing latitude you get nearer and nearer to the center of the earth, and, as a consequence, the gravitational effect becomes greater, which is merely another way of saying that the weight is increased. The second reason is that the greater the latitude, the smaller is the speed with which you are turning around the axis of the earth. For instance, at a latitude of sixty degrees the rotational speed of the earth is exactly one-half of that at the equator. This rotational speed causes a centrifugal force which tends to throw things off the earth; and, though it is not great enough to do so, it does diminish the effect of the attraction which we call gravitation. If this earth were going seventeen times as fast as it does now, an object at the equator would be just about at the

point of being flung into space: and if the earth ever begins to gyrate at that speed, and you happen to be at the equator, I would advise you not to jump, for if you did, you would never come down again. At any other latitude there would still be some attraction which would bring you back, and the safest place for these jumping exercises would be at either of the poles.

Now, though the weight of an object changes with the latitude, its mass does not. You would have found your ten-pound piece so light on the moon, that you could have tossed it around like a ping pong ball. On the other hand, if you would have gone with it to the planet Jupiter, it would have required an exceptionally strong man to lift it, and you would have needed a derrick to raise it if you had been on the surface of the sun. All this shows you that mass and weight are two different things.

A pebble would have all kinds of weight according to where you weigh it: but if you were struck by that pebble while it was sailing toward you at a speed of ten miles an hour, it would not make any difference where you were: at the poles, or at the equator, or at the moon, Jupiter, or the sun. However, if you dropped the thing and it fell on your foot, it would make a difference where this happened. The gravitational force is so much greater on the sun than on the moon, that the pebble would have acquired a very high speed by the time it reached your foot if you were standing on the sun, whereas it would come gently ambling along if the accident were to happen on the moon. The blow would be more serious to you on the sun because the speed is greater; and that speed is greater because the force which gives the mass its weight is greater at one place than at the other. So long as the mass and the speed are the same, it does

not matter to you what the spring scale would register if you should weigh it.

Scientists have weighed, not a ten-pound chunk of lead, or a pebble when it was going at extremely high speed, but a single electron; and they have found that the mass is different for different speeds. Even before they were able actually to weigh this extremely small thing, they succeeded in showing experimentally that such a difference exists, and even in measuring it with a high degree of accuracy.

The result obtained corresponded to what was predicted by the Lorentz formula, and his formula was founded on the assumption that the dimension of a thing was reduced when it was moving. Therefore, if we want to be honest with ourselves, we will have to agree that the Fitzgerald idea was correct, even though we are not able to picture such a behavior of material things to ourselves.

You know, of course, how a pendulum regulates a clock and that if you shorten it your clock will run faster, while the opposite takes place when you lengthen it. If somebody should tamper with the pendulum of your clock, without your knowledge, you would get a wrong impression of time, not to mention that you might miss your train. Now, suppose that somebody, somewhere in the universe, makes two clocks exactly alike in every detail. The pendulums are of the same lengths, and his tests show him that they keep precisely the same time. He gives one of these clocks to you and the other one to my friend on the star. Suppose, further, that the earth is moving in a direction which I shall call up and down, because that is the direction as viewed from the standpoint of the clock. The star, however, is going in a right to left direction. Our movement affects the length of the pendulum of our clock. It makes it shorter,

and, therefore, our clock runs faster; his clock, on the other hand, is not affected that way, because the movement of that star is not in the direction of the length of the pendulum. However, your clock agrees with all the conditions you find around you, and his clock agrees with all his surroundings, so that both of you are sure that your own clock is correct.

As a consequence, he tells you that your clock is fast, and you tell him that his clock is slow. You see then that not only is length affected by motion, but time also. Once more we see how time and space are tangled up into a knot, so that neither of the two comes out undamaged when we try to untangle them.

However, we have always considered a thing as being so much substance; but if the mass, that is, the substance, changes when it is in motion, then we will have to revise this view, as everything is in motion; and, therefore, part of the mass of everything must be due to that motion, be that part large or small. A particle in motion is said to have energy, which means that it is capable of doing work. A pebble in motion has the energy to break your window pane; steam in motion drives the liner across the ocean. We can therefore say that all things are partly matter and partly energy.

It is often the case, that an otherwise perfectly good formula is limited in its application by some consideration of a nature quite strange to the subject for which the formula was developed. For instance, we might have a formula which gives the relation between the amount of coal needed to heat various amounts of water to various numbers of degrees. Such a formula might be quite correct; but when we heat the water up to a point where steam begins to form, we find that we are still using coal, but that the temperature is no longer increasing. The formula

was correct but limited; and the limitation lay in the fact that water, as such, cannot go beyond a definite temperature. Additional heat is used to convert the water into steam.

There may be such a limitation to the Lorentz formula; but if so, it has not yet been found. We are, therefore, at liberty to go with it as far as we like, and speculate as to what would happen if we could give to a body a speed much greater than we are able to do up to the present. For instance, what would happen if we could project a body with the speed of light? The formula shows that the dimensions of that body would have disappeared altogether, and that there would be nothing but energy left; in other words, that a mass, or substance, has been converted into energy; or in still other words, that energy and mass are one and the same thing, but that we recognize it as mass at low speeds, and as energy at high speeds.

Millikan, who has made intensive study of the cosmic rays and who has done many other things of a surprising nature in the realm of physical research, has pointed out that there is some evidence that these cosmic rays somewhere in the universe may be converted into material, which would be nothing else but the changing over of energy into mass.

CHAPTER VI

Just Little Things

WHEN would you call a thing little? Your probable answer is that a thing is little when it is not so big as something else, and that would be about as good an answer as anything. To the elephant a mouse is a little thing; to the mouse an ant is little, and to the ant a microbe would be little, provided the ant knew about microbes. It would seem that we can always go down in the scale of little things. It would seem that it should always be possible to find or, at least, to think of something still smaller than the object we have been considering. However, we find something entirely different in nature. There is a definite lower limit to the size of things. Not only to material things, but even to forces. It seems that this world is built up of particles of a definite size, and that these particles cannot be further divided. We meet no condition in nature which shows us that there are still smaller things than the smallest we have so far discovered. However, this is not saying that we may not have to revise our present opinion a few years from now, when new phenomena have been discovered which call for still smaller units than we are aware of at the present time.

Even the old Greek philosophers had the idea that matter could not be divided without end. They believed that, whatever means might be employed, there would come a time when further division would not be possible, and we are holding this same belief even now. Those bricks of which our house is built are

called molecules—literally "little bodies." However, it has never been possible to isolate a single molecule and investigate its shape, its habits and its morals. So far, the molecule has been elusive, though we have abundant proof of its existence.

At the end of the eighteenth and the beginning of the nineteenth century the molecule lost its position as the smallest thing possible and was crowded out by the atom (literally "indivisible"). Giving it that name was a little previous, for at the present time we are talking about things ever so much smaller than even the atom.

The molecules, then, are built up out of atoms; and it is a peculiar fact that we have never been able to collect as much information about the molecule as about the atom. If we call the molecules our bricks, then the atoms are the grains of sand of which the bricks are composed. It would seem that it should be very much easier to investigate the brick than the grain of sand, but this has not been the case with molecules and atoms. And, come to think of it, it is really much easier to become acquainted with separate individuals than with whole nations or even a single family. Molecules are families of atoms; often not even single families, but whole clans or tribes. There are only about ninety varieties of atoms, but there are millions, and perhaps billions of different molecules. All these molecules together have an unlimited number of traits and characteristics. Just compare a molecule of gold with one of meat and one of water. Atoms, on the other hand, are limited in number and are so set in their ways that, once you have discovered how they choose to act, you can be sure that they'll act that way every time.

Atoms might be called the bachelors or bachelor girls of the material world. They are set in their ways,

and you can predict their behavior, under a given set of conditions, to a dot. The married couples are much less certain; for, be it said, the morals of the atoms are not of the best. Divorce and remarriage are the order of the day. Some families may stay together, rain or shine; in fact, cannot be pried apart except by the most violent measures; but others, and many more, part company on the slightest provocation; and, where you find very large families, or perhaps tribes, such as the molecules of which animals and plants are built up, you will see them in an eternal state of turmoil and dissatisfaction. Every little change of external conditions seems to make them think that a rearrangement is in order.

I should like to give you an idea as to size and shape of the atoms and molecules, but I shall be honest about it and confess that I cannot do it. It is just as impossible for us to form a picture in our mind of extremely small things, as it is to get a realization of very large distances, such as the distances between the stars. I mentioned, a while ago, the wave length of light, and said, lightly, that the wave length of yellow light was about the fifty-thousandth part of an inch. I did not even tell how one can measure it, but perhaps I shall come to that later on. Such a length seems extremely small. However, it is a large distance as compared to some other dimensions we shall meet in the course of our ramblings. In fact, it is perfectly possible, at the present time, to measure such small dimensions by mechanical means, and it is being done every day in many factories.

When we come to the dimensions of molecules and atoms, we find sizes which compare to the wave length of the yellow light, or any other color, for that matter, as an inch compares to a mile. I said that it has not yet been possible to measure molecules

with any degree of accuracy, but this does not mean that we have not some idea of the approximate size of some of them. But before I can tell about this thing, I'll have to talk some more about light. It seems that some knowledge of light is required to get some light on other subjects.

The different colors of light, we know, are different from one another only by their wave lengths, much as the different notes we get on the piano are merely different as to the lengths of the sound waves. As a rule, there are seven octaves on a piano. Every time we strike a note one octave higher than the previous one, we double the number of vibrations, or, what is the same, we cut the wave length in two. As we can do this seven times, the number of vibrations of the highest note is two to the seventh power, or one hundred and twenty-eight times as large as that of the lowest. Even this wide range does not constitute the entire range of sounds which can be perceived by the human ear. This is widely different from the range of the human eye.

The longest light wave which makes an impression on the eye is one thirty-five-thousandth of an inch, and the shortest about one sixty-three-thousandth of an inch in length, so that the entire range is not quite what we would call one octave on the piano. These wave lengths of the different colors give us a means to get some idea of the size of some molecules.

Of course, you have noticed the beautiful colors of soap bubbles. You have seen how some spot on the bubble gradually changes from red through the other colors of the rainbow up to violet, and then back again to red. At the point where you see the red, the complementary color, green, had been killed off by the interference of light. Then some of the film of soapsud evaporated, and the thickness of the film was

such that another color was killed and you saw its complementary color. Now, as we have seen, the thickness of the film must be an odd multiple of a quarter of the wave length of the color which is killed by interference. First, then, we had an odd multiple of the wave length of green and then of some other color, and finally of the complement of violet, and this change occurred because some of the thickness of the film had disappeared into the air by evaporation. The very least amount that can have disappeared in this manner is a layer of one molecule in thickness, and we can easily calculate the reduction of thickness of that film, because it must be the difference between one quarter of the wave lengths of two successive colors. We shall find that this thickness is in the neighborhood of one two-hundred and fifty-millionth of an inch.

What has been evaporated may have been a layer of one, or two, or even more molecules in thickness, but taking for granted that there was only one, we find that the size of this particular molecule is that infinitesimal length: the one two-hundred and fifty-millionth part of an inch.

You have probably marveled sometimes, when you saw some very small insect crawl or fly around, at the almost impossible complication of parts in the tiny little thing. I have done so many a time, and am doing it even now, when I consider that there must be muscles, and nerves, and some kind of skin, and an alimentary canal, and what not in the compass of an almost invisible mite of a thing; and when I do, I stop right then and there, and begin to figure how many molecules there might be in the little beasty.

The insect itself is too complicated in form to allow me to estimate the number with any degree of certainty, and so I imagine in its place a little cube, much smaller in size than even my little insect. Its sides are

one-thousandth of an inch in length, and so the thing is really invisible to the naked eye. However, there are in each of its sides two hundred and fifty thousand molecules, and if we calculate the total number of molecules in this little cube we get the astounding figure of 15,625,000,000,000,000; fifteen thousand, six hundred and twenty-five million millions. Is it any wonder that they can be grouped and combined into innumerable organs? Why, each organ can still have millions, or even billions of molecules.

I am not going to trouble you much with such large numbers. Numbers with twelve ciphers in the tail do not tell very much, but I cannot resist the temptation to ask you to develop such a number yourself. If the wave length of violet light is one sixty-three-thousandth of an inch, and the light travels with a speed of one hundred and eighty-six thousand miles a second, how many of these waves reach us in one second? You see, just as with your radio set, if you know the wave length of a station, you can find the number of kilocycles (thousand cycles) by dividing the length of the wave into three hundred thousand, (the speed of radio transmission is the same as that of light, namely 300,000,000 meters, or 300,000 kilometers or 186,000 miles). Following the same procedure here, we must divide the length of the violet light wave into the speed of light. Multiply sixty-three thousand by twelve, and you know how many there are in a foot. Multiply this by five thousand, two hundred and eighty and you know how many there are in one mile; and then multiply this again by one hundred and eighty-six thousand, and you find how many waves strike your eye in one second.

You may have thought it strange, sometimes, that you can get a picture with your camera with an exposure of only a one-hundreth of a second, and

wondered probably more, when reading of others who have made pictures with an exposure of only a one-thousandth of a second; but look at the answer to your problem, and see how many billions of waves strike the photographic film in the time of the shortest exposure you ever read or heard of.

Doctors were wise when they invented the pill. It is not so much that the pill is easier to take than other medicine, for that is not the case for some people, but that the patient is compelled to take the whole dose, or nothing at all. Acting on this principle I'll keep right on telling you about these impossibly small things which seem to be the favored pets of the scientists.

For instance, when I said that the entire range of the visible vibrations was not quite one octave, I did not mean that there were no other vibrations of the same nature as those of light. Immediately below the red, you find other vibrations which you can note by the fact that they give heat; and this kind extends almost three octaves downward, that is, with longer and longer waves and less and less vibrations per second. Still further down, we find what the scientist calls the Hertzian waves, and what we call the radio waves. They extend another six octaves, or perhaps more. Then again, above the violet you find first the ultra-violet rays, then the X-rays, then the gamma rays, and finally the cosmic rays. This adds another seven octaves to our piano, which has now altogther fifteen octaves. The longest waves are generally expressed in miles or kilometers; the ordinary light waves, those which strike our eye, are expressed in thousandths of an inch; and the others are so short that it has been found necessary to invent another unit of length, or rather, another name to escape the necessity of writing fractions with an endless number of ciphers.

This new unit is the Ångström, so named after a Swedish scientist who first proposed it. The Ångström has a length of a one-hundred-millionth of a centimeter, or about the two-hundred and fifty-millionth part of an inch, and even this does not seem to be short enough to avoid the writing of fractions, for some of the cosmic rays have a wave length of the one-thousandth part of an Ångström.

Out of this wide range of more than fifteen octaves, our eye takes notice of less than one. Our skin perceives a few longer ones and is warmed by them and, perhaps, a few shorter ones and gets tanned; but the rest of all these vibrations is beyond the range of our senses. It takes something finer than the human eye or the human skin to detect these prime agents of nature, namely, vibrations. Instruments and mathematics have opened a new world for us. Perhaps the greatest difference between man and animal is that man is not limited by the scope of his senses.

Atoms, for instance, are too small to be seen, even with the aid of our best instruments. Yet, we know a great deal about them, weight, size, what they are made of, how they behave in relation to each other and much more. We have learned to distinguish them even if there are only a few hidden in a large mass of other kinds. They have, by the knowledge we have of them, become of such absorbing interest to us that they deserve a new chapter.

CHAPTER VII

More Little Things

ATOMS were long considered the smallest things in existence, but lately they have lost that honored position. We now believe that there are other things much smaller than atoms—the things of which atoms are made. However, even the atoms themselves are small enough to be treated with respect. We can ask so many questions about them to which the answers are so hard to get; we can find so many things about them which are the answers to questions that have never been asked; the knowledge of their qualities has led to the discovery of so many useful substances, and withal they are, even now, so much of a riddle to us that they may well be considered the biggest things in the sciences of physics and chemistry, though they are the smallest ones to all the rest of the world.

Perhaps the first question which has come to your mind while I was indulging in my preamble was: how do you know that there are such things as atoms, if they are so small that nobody can see them even with the best instruments in existence? That question is a good one, for it shows doubt; and doubt is one of the first requirements if you want to obtain correct knowledge. Faith is a fine thing in your spiritual life, but a very poor one if you want to develop your mind and gather the riches of knowledge.

Suppose that you were on one of those old-time trading vessels which sailed to strange lands, there to deal with the natives and trade glass beads and pieces of calico for their products and treasures. Suppose that

you stop at one point where the natives are very ignorant and where the only thing you can get for your beads is some grain, which you are perfectly willing to accept because you are in need of it. Suppose further that when you get the grain and weigh it you find that, every time, there is a multiple of a certain amount; for instance, one time there is five pounds, another time twenty pounds, still another time fifteen pounds, etc. Would you not come to the conclusion that these savages must have a measure or weight which they use when they prepare the quantity of grain in trade for your trinkets? It may not be five pounds which is their unit; it may be two and a half, or one and two-thirds, or even a single pound; but it seems fairly sure that there is some kind of unit, and if you find that you get five pounds for a string of white beads and ten pounds for a yard of calico, you also know that in their estimation the latter is worth to them twice as much as the former. Not only are you sure that they must have a unit, but you are also sure that this unit must be such that it is either five pounds or else a simple fraction of that amount. If they have other products to trade for your beads and you find that this product is always delivered in multiples of nineteen ounces—for instance, thirty-eight ounces for a string of white beads—you will come to the following conclusions: first, they have another unit to measure this new product, and second, there is in their minds a fixed relation between the two units. In our case it seems that they have established for themselves the relation that the values of the two kinds of product bear the same ratio as five pounds to thirty-eight ounces.

We have a similar case when we deal with the savage little atoms. We can combine two ounces of hydrogen with sixteen ounces of oxygen, and there will be

nothing left of either of the two. The merger is perfect. We can take any quantities, and so long as we take eight times as much oxygen as hydrogen there will not be any residue of either; the merger will always be perfect. But when we change the proportion, a residue will be left of the one which was in excess of this proportion. No matter how large or small we make the quantities, we must come to the same conclusion as when we were trading—namely, that there is a unit by which the quantities of the two elements are measured. This unit is our atom.

If we now combine the hydrogen with some other element, say chlorine, we find that two ounces combine with seventy ounces of chlorine. (This figure is not entirely correct, but near enough for our discussion.) And now, if we combine some chlorine with silver, we find that thirty-five ounces of the first material need one hundred seven ounces of the latter to make a perfect merger. (Again these figures are only approximate, because I have no desire to trouble you with fractions more than is absolutely necessary.) So it it would seem that the unit of hydrogen is two of a certain weight, and that of oxygen sixteen. That of chlorine would then be seventy, and that of silver two hundred fourteen, because that much silver was needed to combine with the seventy units of chlorine. But now something else will have to be considered. Our two ounces of hydrogen took up a certain amount of space and the sixteen ounces of oxygen required exactly half as much.

As we are rambling through science we shall meet many things which we shall have to accept without proof. If we did not, we would never get home again, and so I shall ask you to believe for the present that the following is true: when two different gases occupy the same amount of space and are subjected

to the same pressure and have the same temperature, then there are the same numbers of molecules in these gases. If we had confined our two gases, oxygen and hydrogen, in receptacles; and if they were of the same temperature and pressure, we would have found that the hydrogen needed twice as much space as the oxygen and that, therefore, there were twice as many molecules of hydrogen as of oxygen. One ounce of hydrogen contains as many molecules as sixteen ounces of oxygen. We shall see later that each molecule of each of the two gases is built up of two atoms so that we may say that one ounce of hydrogen has as many atoms as sixteen ounces of oxygen. Another way of stating this is to say that one atom of oxygen weighs sixteen times as much as an atom of hydrogen.

If we call the weight of one atom of hydrogen *one* (one of something), then we might just as well call the weight of one volume *one* (one of something else) and, in the same manner, we can call the weight of a corresponding volume of oxygen *sixteen.* We found that two ounces of hydrogen combined with seventy ounces of chlorine, so that a certain volume of chlorine weighs thirty-five times as much as the same volume of hydrogen. We can, therefore, say that the weight of an atom of chlorine is thirty-five. The same reasoning shows us that an atom of silver weighs one hundred and seven. These figures, 1, 35, and 107, are the relative weights of the atoms of these three substances. These figures are called the atomic weight; they represent the relative but not the actual weights of the atoms.

This peculiar habit of most atoms of combining with each other is in itself a remarkable thing and has made the scientists ask what really takes place when one atom mates with another. It makes one think of marriage, of man and woman. Not so very

long ago scientists called some of the atoms positive and others negative, but they were not bold enough to say whether the men or the women were the negative ones. Take, for instance, our hydrogen and oxygen atoms, bring them together, excite them to the proper state of elation by an electric spark, and they'll forthwith marry. (I hope the reader will notice that here, as with men and women, some sparking takes place before marriage.) Oxygen seems to take the place of the man, for it requires two wives before it is satisfied. Yet, it cannot be said to be an incurable bigamist, for sometimes it seems to behave in a more modest manner. Under certain conditions oxygen will take only one wife, but only when one of its friends is willing to do so at the same time. We then find a happy family of two gentlemen and two ladies: our peroxide of hydrogen. However, the true nature of the stuff will show itself again as soon as the conditions are right; for, in certain cases, one of the oxygen atoms will throw the other one out of the combination and take to itself the other's wife—something which seems to occur among us humans, too, once in a while, if we are to believe the daily papers. After the scrap is over, the oxygen settles down to what, for it, is the proper family life: marriage with two wives. The poor atom which has been so unceremoniously thrown out of the common home must needs console itself by attacking some microbe, which is trying to make trouble for us when we have cut ourselves. The now happy family of three we call water.

Though oxygen seems to be the bigamistic male when it sins against the hydrogen atom, at other times it is just as much sinned against. Where it requires two wives, the carbon atom seems to need four before it is entirely satisfied. Carbon can actually combine with one, two, three or four atoms of hydro-

gen, which leads to four different substances. It seems to have four arms, and it can have a hydrogen atom on each one. Now, here comes a thing which makes it difficult to go on with our fancy of male and female atoms. Carbon can also combine with oxygen. It can do so in two ways: it can take unto itself either one or two atoms. Of course, if we are determined to keep up our little play of representing the atoms as men and women, we can manage this particular case in some way. For instance, we can say that carbon resembles the women of Thibet, where a woman can have more than one husband; but soon we shall find that things become too complicated and we shall have to find another simile. No scientist has ever spoken of atoms as being male and female, but they have been spoken of as being positive and negative, and then hydrogen was considered positive and oxygen negative, which was very nice for the ladies but not very flattering for the gentlemen. After all, this grouping of the elements into positive and negative ones did not do away with a difficulty, the fact that sometimes an element was in the one group and sometimes in the other. For instance, some of the metals, such as tin, would sometimes act in a positive way and then again in just the opposite manner.

There was also much speculation as to what caused some elements to be satisfied with one atom of hydrogen (or some other element), while others required two, three or four. For lack of exact knowledge the world had to be satisfied with some symbolic picture. For instance, atoms were pictured as being provided with hooks. Of course, nobody thought that they really had hooks, but it presented us with a picture easy to imagine, and therefore helpful in the analysis of known actions of the atoms and in the forecasting of new and, as yet, unknown combinations.

Hydrogen was pictured as having one hook, oxygen as having two, nitrogen as having three, and carbon as being provided with four. More than four were not found to be necessary to explain all the known facts, though, at times, some elements, such as iron and aluminum, acted as if they had six. The peculiar behavior of oxygen in sometimes taking only one atom of hydrogen—or perhaps I should say, of two atoms of oxygen combining with two atoms of hydrogen (peroxide)—and sometimes requiring two atoms of hydrogen for one of oxygen, was easily explained by the hook method. When water was formed each of the hooks of oxygen was connected to the one hook of an atom of hydrogen; and when peroxide of hydrogen was the product, it was imagined that two atoms of oxygen went, so to say, arm in arm, and then two hydrogen atoms were hooked onto the free arms. All in all, it was a very good pictorial representation of the facts, but, of course, one should not take it as the exact truth.

If you imagine the atoms as having these hooks, it becomes very easy to understand why some of the elements can enter in so many ways in so many different compounds. For instance, take carbon with its four hooks. It can satisfy two of its hooks with the two hooks of an atom of oxygen, and leave the two others unburdened. Here we have the noxious carbon monoxide. Heat this gas in the presence of oxygen and we get carbon dioxide, or, as it is commonly called, carbonic acid, which is the harmless material which makes the soda water fizz. All four hooks of the carbon atom are now satisfied. Or, again, one of the hooks can be joined to one of another similar atom, leaving three hooks of each free so that there is a chance of making six more connections. Any number of carbon atoms may be joined together, and the

connection between any two may be with one, or two, or even three, but not with four, for then there would not be any hook left to unite with some other atom.

When an atom of one kind does not find one of another kind to hook onto, it combines with one of its own tribe; that is, it generally does, but not always. Two atoms of hydrogen form one molecule of that gas. More than two could not hook up, because each one has only one hook to offer the other. On the other hand, two atoms of oxygen have four hooks together and need only two to combine. As a matter of fact, however, they leave no hooks unconnected. They seem to act as two friends, meeting each other after a long separation, stretching out two hands to grasp both hands of the other.

However, sometimes they act differently. Atom *A* gives one hook to *B* and one to *C*, while *B* gives its other hook to the free hook of *C*. Here we have *ozone*.

As I said, the hook idea gives us a nice picture, but, after all, it does not explain anything. Of course, it did not satisfy the true scientist. He had given himself and us a picture, and he had given specific names to the quality of the atoms to act as if they had one or more hooks; he called the ones with one hook univalent, those with two hooks bivalent, those with three trivalent, and the ones with four tetravalent; but he was not able to connect this peculiar behavior with some other facts which were already known.

Summing up what was known about the atom, we find this: the relative weights of the various atoms was known; so was their valency, and, of course, their chemical behavior. Innumerable compounds had been investigated, and numerous new compounds had been originated. The physical conditions under which various atoms would combine or part company was known with great precision, and many other things besides.

However, chemical knowledge stood by itself. There was no connection with physics. It used to be said that physics was the science of molecules, and chemistry that of the atoms. A physicist and a chemist had nothing to do with each other, no more than a painter and a composer of music. The first two are both scientists, and the other two both artists; but they work along different lines and with different materials, and they concern themselves about different subjects.

Then electricity stepped in, in an entirely unexpected manner, and joined the two, so that now it would take a clever man to say where the one begins and the other ends. It was this way:

It had long been known that electricity can decompose certain compounds into its component elements. For instance, it could break up water into oxygen and hydrogen, or a silver salt into the metallic silver and an acid, or do the same to a copper salt; and this knowledge was put to the practical use of silver or copper plating. But here again, this knowledge stood by itself. Fundamental knowledge was lacking. In both physics and chemistry, no knowledge is considered complete until it can be expressed in figures. Measuring and weighing are the two essential parts of scientific observation. As soon as some careful measuring and weighing had been done about this ability of electricity to decompose various compounds, a connection was found which joined the two sciences together in a most beautiful way.

CHAPTER VIII

A New Peg to Hang Our Things On

IT was found that a certain amount of electricity was required to obtain a given quantity of hydrogen when water was electrically decomposed. If five amperes, working during one hour, would set free a certain amount of hydrogen, this amount would be set free every time we let five amperes work on water for one hour. It was also found that if one lets the same amount of electricity work for the same length of time on a silver salt, a quantity of silver is set free, which weighs one hundred and seven times as much as the hydrogen. You remember that the atomic weight of silver is one hundred and seven, meaning that an atom of silver weighs that many times the weight of an atom of hydrogen, of which the atomic weight is one. Similar observations were made with other compounds, and many were found which would give an amount of deposited material as many times greater in weight than the amount of hydrogen (produced in the same time and with the same amount of electricity), as can be expressed by the atomic weight. If one gram of hydrogen would be deposited, then ten grams would be deposited of a material of which the atomic weight was ten, and fifty grams if the atomic weight was fifty.

Suppose you lay down some apples which weigh six ounces each, and another pile of apples which weigh twelve ounces each; and suppose I weigh them and find that the second pile weighs just twice as much as the first; then I can tell you, without counting

them, that both piles contain the same number of apples. Similarly, we can now say that the same number of atoms are deposited by the same amount of electricity and this, whether an atom weighs one, or a hundred and seven, or any other amount.

However, it was not always this way; some elements were deposited at a lesser rate; sometimes only half the expected amount, sometimes a third or a fourth. It was further found that only one half the expected amount was deposited when the atoms of the substance were bivalent, one-third when they were trivalent, etc. In other words, a bivalent atom required twice as much electricity as a monovalent one. To come back to our old way of expressing it, each hook of an atom required the same amount of electricity, regardless of the specific weight of the atom. In still other words, a certain definite amount of electricity was needed to disengage a pair of hooks. This amount of electricity was called an electron. So far as electrolysis goes then, the electron is the unit of electricity.

Something else was found in this connection. The material so deposited was found to be either electrically positive or negative, so that it was evident that the deposited material carried its electrical charge with it.

When we do copper plating, the object to be plated is hung from a wire on the negative side of the circuit. A plate of copper is hung from a wire on the positive side, and both are submerged in a liquid, called the electrolyte. In the case of copper plating, this electrolyte is a solution of copper sulphate. What seems to happen when the current is turned on is this:

A molecule of the copper sulphate is split up into an atom of copper and a molecule of sulphuric acid. This happens next to the copper plate, or, at least, that is the picture which we may form for ourselves,

to get a somewhat clearer idea of the entire process. The molecule of the acid forthwith attacks the copper plate and becomes again a molecule of copper sulphate. Meanwhile the atom of copper which has been set free, and which carries a charge of electricity (an electron), attacks an adjoining molecule of the electrolyte, and, itself, becomes once more a molecule of copper sulphate. Or, if you prefer it, you may think that it has given its charge to the object to be plated, at the other end of the vessel; in other words, that it has traveled there, carried by the current. It attaches itself now to the object, because its charge is positive, and the object is at the negative side of the train.

This then seems to be the way in which the electric current is carried in liquids: that units of electricity are carried by the atoms. These individual units of electricity, these electrons, can be either positive or negative. If an atom should carry a negative charge, and it should meet a positive electron, it would be neutralized. It would also be neutralized if it met another atom which carried a positive electron, and the two would then combine, and this is what is supposed to happen when two monovalent atoms form a compound molecule.

Some elements carry negative electrons and some positive; and this was formerly believed to be the reason why some elements will pair and others will not. Though this explanation of chemical phenomena is very nice, it did not satisfy the then existing scientists very long. There were supposed to be two different kinds of electrons and this was considered as being one too many. Furthermore, if this was the way in which electricity is conducted in a liquid, how was it conducted in a wire, or in a gas? You will remember, a hypothesis must not merely satisfy one known

phenomenon, but it must satisfy all the known ones; and so we were once more at a standstill.

However, another phenomenon was observed which, at first, seemed to have no relation whatever to the foregoing, but which proved to be the key which opened the door wide and allowed many hidden things to come to light.

It was well known that a dry gas does not conduct electricity. This was known even in the earliest days of electrical research. It could easily be demonstrated with that simple piece of apparatus called the electroscope. This consists of two strips of gold leaf hung from a piece of metal wire which, in its turn, is supported in a stand, but which is insulated from it. Rubbing a piece of sealing wax would make it electric, and when this piece of wax was brought against the rod carrying the gold leaf some of the electrical charge was given to the two leaves. Of course, both leaves were similarly electrified, and therefore repelled each other. The two leaves would stay away from each other for a long time, so long as the air was dry, showing that dry air is a poor conductor.

The discovery which was to shed light on many dark problems was this: that a flame, or a glowing wire, or an electric arc or spark would make air a conductor, when, without it, there was no evidence of conductivity at all.

You have probably seen a Geissler tube. It is a glass tube, often twisted and wound into fanciful shapes. Wires are led into both ends. If a current of the proper voltage is sent through the wire the entire tube becomes filled with a beam of light. The tube contains gas at very low pressure. Most of the gas has been exhausted, but it is essential that some gas should be left. The color of the light depends on the nature of the gas in the tube.

It is apparent that, in the case of the Geissler tube, gas conducts electricity, for the two wires are separated by the entire length of the tube. The Geissler tube was further developed by Crookes, and nowadays one speaks no longer of the Geissler, but of the Crookes, tube.

Figure 6 shows such a tube. At one end is a small metal plate, and not far from the other end is another plate, somewhat larger and of a distinctive shape—say square or triangular. The two plates are connected to the terminals of an electric circuit. We will assume that the first-named plate, the small one, is connected to the negative terminal. The tube is filled with a gas

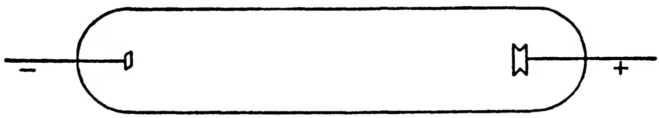


FIG. 6.

under very low pressure, less than the one ten-thousandths part of an atmosphere. (The normal atmospheric pressure at sea level is 14.7 pounds to the square inch.) The source of electricity is not our electric light system, because the voltage would be too low, but is furnished by an induction coil which gets its power from a battery.

Many experiments in electricity require the use of a battery. As a rule, our domestic electric light systems give alternating current. In the case of our present experiment this would give alternately positive and negative electricity to the negative end of our tube, and this would not do for what we want to show.

As soon as the current is turned on we'll see a glow between the terminal plates. We can clearly see that this glow originates at the negative end, for the shadow of the plate at the positive end is thrown on

the glass. We see also that this light coming from the cathode (the negative terminal) goes in a straight line to the anode (the positive terminal), for the shadow is clearly defined and has the shape of the anode plate. This, in itself, is a beautiful experiment, but so far it has not told us very much. We now bring a magnet close to the tube, and we see the shadow shift its position, as if the beam of light were bent. If we should make a corresponding experiment with ordinary light—say that from a candle—we would not find a similar result.

We can easily carry out this check experiment. We place on the table in a darkened room a candle, and in front of it a metal screen, or a piece of thin cardboard, in which a small hole has been punched, so as to allow only a narrow beam of light to get beyond the screen. We place a small object some distance in front of the screen, and still some little distance further another screen, preferably white, so as to see clearly the shadow of the object. Bringing a magnet close to the cone of light does not change the position of the shadow on the screen, no matter how strong this magnet may be. This shows that what we see in the vacuum tube is not ordinary light. It looks as if there is some substance going from the cathode to the anode, and that this substance has the power to light up the anode plate, and even to light the space between the two plates.

We will have to make some other experiments to see more clearly just what is going on in our tube. We will take another tube, constructed as shown in Fig. 7. The only real difference between the two tubes is that this time there is no target to throw a shadow. The terminals are at the two ends of the tube, and both terminals are small plates of similar shapes. You will notice that there is a projecting part at *O*.

This part can be connected to an air pump. Until now the air in the tube is of the same pressure as the atmosphere. When we turn the current on, nothing happens, but now we begin to exhaust the air from the tube and when we reach a point where the pressure is low enough, we see a beautiful light display. There is a faint glow around the cathode, then comes a dark space and still further is a glow which extends to the anode. If we keep on reducing the air pressure, we see the dark region growing more and more

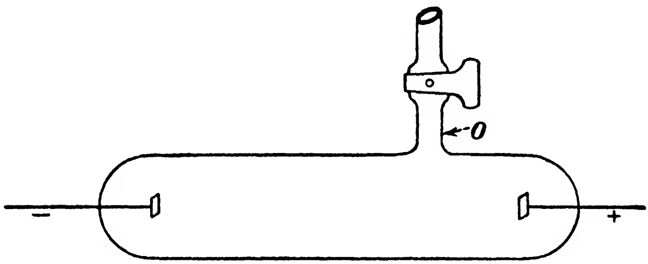


FIG. 7.

toward the anode, until finally it reaches the other end of the tube. As soon as the dark space reaches the glass wall of the tube we see a beautiful display of phosphorescence.

There seems to be something which hits the far wall, not merely some light, but a substance. Let us make another experiment. We will charge our little electroscope and place it in a glass chamber. We will suppose that the air is dry. If it were not, we could make it so. The glass chamber has two outlets from which glass tubes project; one of these is connected with some device which draws the air from the chamber, say an air pump, and the other is bent and ends in a funnel, under which we can place a burning candle. The entire apparatus is diagrammatically shown in Fig. 8.

The air in the chamber being dry, the leaves of the electroscope stay apart until we place the candle under the funnel and begin to draw the air from the chamber. As soon as we do this, we see the leaves collapse toward each other, which shows us that they have lost their charge. We ask ourselves if this can be due to the fact that the air coming in from the candle is hot; and, in order to find out if this is so, we break the connection between the chamber and the funnel and rig up an additional piece of glass tube which we bend and submerge in ice cold water,

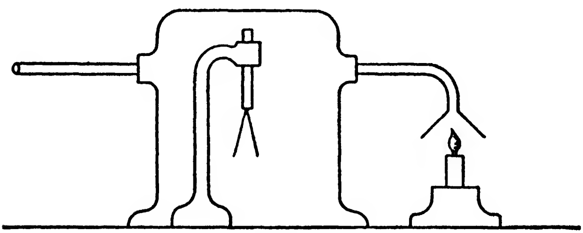


FIG. 8.

so that the air coming from the candle is cooled before it enters the chamber. We see that, again, the two leaves collapse. We know, therefore, that it was not the heat which made the leaves collapse.

We carry out still another experiment. We let the end of the tube which is connected to the funnel dip into a closed vessel, partly filled with water, and that part of the tube which is connected to the chamber is also dipped in the vessel, but not into the water. When the apparatus is arranged in this manner we can draw the heated air from the candle through water; and, whether the water is hot or cold, we see that the air coming from the candle no longer has the power to discharge the electroscope. It seems that something was left behind in the water, something which had

the power to remove or neutralize the electrical charge on the gold leaf.

Suppose we had our electroscope charged by approaching it with a bar of sealing wax, which had been rubbed, and that then we approached it with a bar of glass, also rubbed; we would see the leaves, which at first were spread apart, collapse as soon as the bar of glass came near enough. It would have been a case of one kind of electricity neutralizing the other.

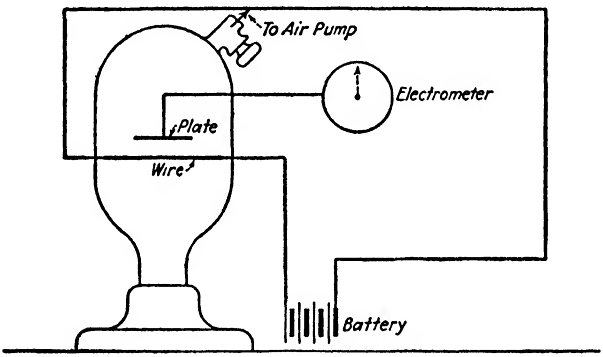


Fig. 9.

We come now to the conclusion that what discharged the electroscope in our experiment with the candle was also the opposite kind of electricity, and that this charge was carried by the air coming from the flame. Some of the particles of this air were changed. What that change was can be very clearly shown by still another experiment.

Figure 9 shows the piece of apparatus we will use for this experiment. We have a glass bulb which can be connected to an air pump. Through the walls of this bulb, a wire extends which, on the outside, is connected to the terminals of a battery, so that we can bring it to incandescence. Immediately above the wire there is a

small metallic plate from which a wire extends through the glass. This wire is connected to an instrument which indicates the presence of electricity, and also whether this electricity is positive or negative. We heat the wire gradually, and notice that the instrument indicates that the plate is positively charged. This indication grows stronger and stronger as the wire grows hotter, but only up to a certain point. In fact, if we go on heating the wire the instrument indicates a diminishing charge. If now we exhaust the air from the bulb, we notice that the instrument indicates a negative instead of a positive charge. It would seem as if the hot wire had broken up some particles of the air in the bulb into two parts, one of which was positively charged, and the other negatively.

We may think that the atoms of air were split up into two uneven parts, the positive part being large and the negative part small. At first, at low temperature, the large part had enough energy to reach the plate, but the small part had not. As a consequence, the plate showed decidedly positive. Later on, as the temperature rose, the small parts also acquired enough energy to reach the plate and neutralize some of the positive particles. This would explain why, with rising temperature, the plate became less strongly charged. Still later, when the air was exhausted, the negative particles met so little resistance, on account of the reduced pressure, that all of them could reach the plate, while the large particles, on account of their greater mass, were not so much affected by this reduced resistance, and so only about the same number as before would reach the plate.

This last statement makes me think of an old misconception. Many people seem to think that a one-pound piece of lead falls slower than a ten-pound piece, notwithstanding that several hundred years ago the

contrary was proved by Galileo. Of course, they say, it is not so noticeable with two pieces of lead, but if we had a pound of lead and a pound of feathers there would be a decided difference. And so there would be, if we let them fall through the air. If, however, we let them fall in a vacuum, we will see them fall at the same speed; and that experiment is one of the standard experiments of the lecture room. The reason why they do not fall with the same speed in air is that the compact piece of lead meets so much less air resistance per unit of weight, on account of its small area. This same thing took place in the bulb. The light piece was retarded more by the air than the heavy piece, but this handicap was removed when the air was exhausted.

CHAPTER IX

Things to Hang on the New Peg

LET us see what conclusions we can draw from all the foregoing experiments, and if there is really some relation between them, and what happens in the electrolyte when we do copper plating.

Let us imagine that the atom was really torn in two and that one of the pieces was much smaller than the other, as we assumed in the previous chapter. We saw that the smaller piece was negatively electrified. Before it was separated from the atom it must have been held by the attraction of the rest of the atom which, therefore, must have been positive. This, we found, was actually the case, for so long as these small pieces did not have enough speed, or met too much resistance, the plate in the last experiment was positively electrified. In the electrolyte, too, the atom was torn in two, and one part—the positive—went to the object to be plated and the other part to the anode. In the case of our copper plating experiment, there was not a single atom which was so divided, but an entire molecule; yet it is apparent that one electron was torn away from the copper atom and that there was one electron missing on the rest of the molecule. When an atom has been deprived of one of its electrons it is called an *ion*, which means wanderer.

The same thing—that is, the separation of an electron from an atom—happened when the wire in our last experiment was heated, and we say that part of the air in the bulb was *ionized*. Ordinary air does not conduct electricity, but ionized air does, and this is

the reason why in the other experiment with the gold leaf electroscope the leaves collapsed when ionized air came into the chamber. When we bubbled this air through water, the ions were left there and the air entering the chamber was no longer conducting. We can also understand now why a magnet deflects the rays in a Crookes tube. The air in it must have been ionized. It looks as if electrons have been shot off from the cathode, and that they, striking the opposite wall of the tube, caused the phosphorescence. We are sure that they were the negative particles, because they went to the positive end of the tube.

Naturally, the first things the scientists asked about were the size and weight and speed of these electrons. They seem to be hard questions to answer, for the particles are too small to be handled individually; but then, there are very few things in the science of molecules and atoms which can be measured or weighed by direct methods. We have already seen how the scientist helps himself when we discussed the experiment of Michelson and Morley, or when we saw how the speed of light is measured. In the case of the electrons, too, he had to employ indirect methods and he made use of the fact that a magnet bends the rays that come from the cathode, and which, quite properly, have been called cathode rays.

The simplest of the three problems is the one about the speed of the electrons in the Crookes tube. A diagram of the apparatus used to determine this speed is shown in Fig. 10. There is a modified Crookes tube, the modification consisting of the addition of a third terminal, which we will call the target because it is to this plate that we will try to deflect the rays. We will do this by the application of a magnet, and we will use an electromagnet because by doing so we will have it in our power to regulate the strength

of the magnetic field. When this field is of the proper strength, the rays strike the target instead of the anode. J. J. Thomson, another famous physicist, used a somewhat modified arrangement which gave him excellent results. Instead of deflecting the stream of electrons between the cathode and anode, he let this stream through a small hole in the anode itself and deflected the stream after it had passed through this window.

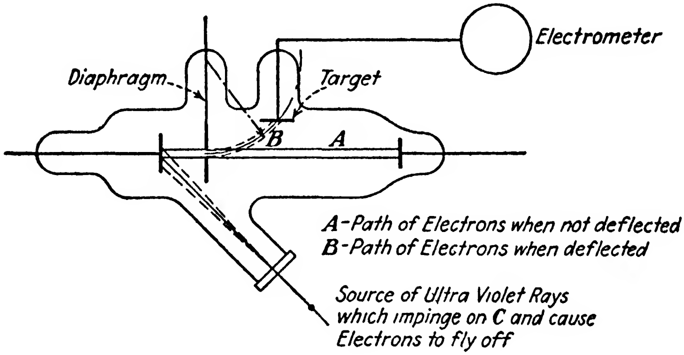


FIG. 10.

From this moment on we must ask the help of mathematics. It can be shown that the rays, when deflected, must go along the arc of a circle and that the radius of the circle depends on the relation between the speed of the electrons and the strength of the magnetic field; that is to say, with a given strength of the magnetic field the radius will be smaller with low speed of the rays, and with a given speed of the rays the radius will be smaller with increased strength of the field. When the field strength has been properly adjusted we know all the elements necessary to calculate the speed of the rays. We know the various dimensions of the tube, such as the distance from the cathode to the target—or rather, I should say, from

the diaphragm to the target—we also know the strength of the magnetic field, and, the target being connected to an electrometer, we further know the amount of electricity carried by the rays. As nobody can find much pleasure in going over the calculations made by somebody else, I'll skip the formulas used and the way they were employed.

The speed of the electrons depended on the voltage difference between the cathode and anode. It is plain, of course, that if this voltage were extremely low, there would not be any cathode rays at all, and it can readily be imagined that the phenomenon becomes more and more marked when the voltage is increased. The voltage which was used was measured. This measurement was also one of the elements entering into the calculation. There was still another item which appeared in the formulas used—namely, the mass of a corpuscle—but, fortunately for us, this was canceled out in the final operation. Then there was still another item, but this also was canceled out—that is, the electrical charge or the amount of electricity carried by the electron.

Though these two items, the mass and the charge of the electron, were both dropped out of the calculation when we wanted to find the speed of the electrons, and though there are not enough data to determine either of them by itself, our experiment did give us enough figures to find their ratio; that is, we can calculate the value of the fraction: electrical charge divided by the mass of the electron. This ratio was found to be ten million.

In order that there shall be no confusion as to what is meant when figures are given in scientific papers or books, scientists have agreed on a universal system by which measurements, weights, times, forces, energy, work done, etc. are given in a manner understood by

all. Therefore, when we say that the ratio between mass and charge is ten million, we mean that if we could give a figure for the mass of an electron and one for the charge, each expressed in its proper units, the latter figure would be ten million times the former. It is something like this: if we could say that there is a definite ratio between the height of a person and his weight, as some people nowadays seem to think they can, we might say that the weight should be twice the height. For instance, if a man is five feet six inches in height he should weigh one hundred and thirty-two pounds. You see that each of the two elements is expressed in the proper terms: height in inches and weight in pounds. So it is with the ratio between mass and charge: each is expressed in the proper units and the ratio is between the figures which express the values of the two things each of which is measured in its own system.

It is quite natural that, as soon as this ratio was found, there was an attempt made to find the value of each of the two terms. As will be seen, this was not nearly such an easy thing to do as to find the ratio between them. Many efforts were made, all with more or less success, but none with such a degree of certainty that the scientific world dared to say: *this* is the weight of an electron. It was not until Millikan made his now famous experiments that we could say with certainty how much an electron weighs. It is extremely difficult to form an idea of the smallness of an electron; the best possible illustration falls short of reality, and figures are merely confusion. However, I cannot resist the temptation to quote what Millikan himself says of the size of this most interesting building material of nature. He says:

"Perhaps these numbers [the amount of the electrical charge and the number of electrons in a

certain weight, mentioned in some of his discussions have little significance to the general reader who is familiar with no electrical units save those in which his monthly light bills are rendered. If these latter seem excessive, it may be cheering to reflect that the number of electrons contained in the quantity of electricity which courses every second through a common sixteen-candle-power electric lamp filament, and for which we pay 1/100,000 of 1 cent, is so large that if all the two and a half million inhabitants of Chicago were to begin to count out these electrons and were to keep on counting them out at the rate of two a second, and if no one of them were ever to stop to eat, sleep, or die, it would take them just twenty thousand years to finish the task."

To weigh such a thing is a wonderful achievement, and yet it has been done with a degree of accuracy far greater than that with which your butcher weighs your steak, in fact with an accuracy at least as great as the druggist requires when he weighs the different ingredients for your potion. At that, the principle Millikan employed was a relatively simple one and this may have been the reason why nobody thought of it before. He took a drop of oil and let it fall through the air. The drop was exceedingly small so that it fell very slowly, so slowly that it was possible to watch its progress downward through a short focus telescope in which there was a pair of cross hairs. He could observe the fall of the droplet and note the time required for it to travel from one cross hair to the other. The droplet was traveling in the space between two metallic plates which could be charged electrically, the one positively and the other negatively. He could then place an electron on the back of that droplet and note the rate of fall again. This time the electrical charge of the droplet might accelerate or retard the fall, depending

on the nature of the electron—that is, whether it would be repelled or attracted by the upper plate.

Now, all this sounds very simple, but when it comes to making a droplet so small that it floats slowly down through the air, and having the air so still that the droplet goes straight up or down and never turns either to the right or to the left, and above all, taking an electron and placing it on that droplet—

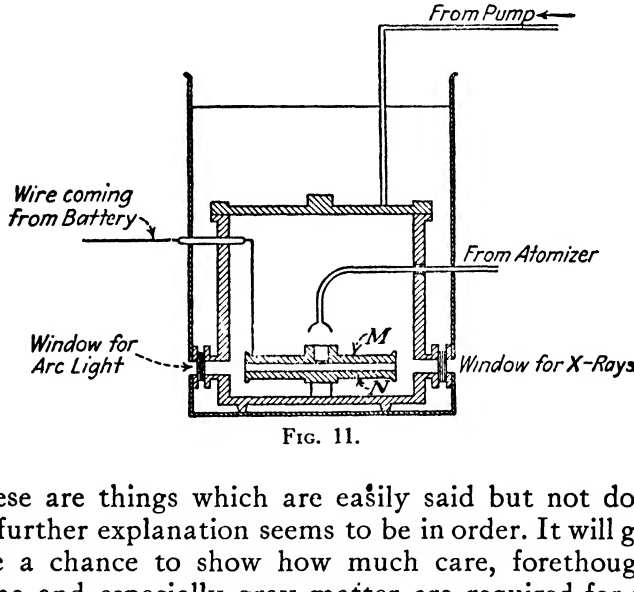


FIG. 11.

these are things which are easily said but not done. A further explanation seems to be in order. It will give me a chance to show how much care, forethought, time and especially gray matter are required for the fundamental experiments of the present day science.

Figure 11 shows in diagrammatic form the apparatus used by Millikan for the determination of the value of the electrical charge carried by an electron or an ion. *M* and *N* are brass plates which can be electrically charged from a storage battery of 10,000 volts. Please compare this with the voltage of the storage battery of your car. The plates were made flat to

within about one twenty-five-thousandth of an inch and they were insulated from each other by three pieces of glass, which were of the same heights. In fact, there was no discoverable difference in their heights at all. The plates were surrounded by a ring of black material so that, normally, the entire space was in darkness. However, there were three windows in the black ring. A strong arc light could throw its light through one of these windows and thus illuminate the droplet, which would then appear as a bright speck against a dark background. A telescope with short focal distance was directed to the second window and so gave one a chance to observe the droplet. The third window was used to give admittance to the X-rays from an X-ray bulb outside the ring. These X-rays were for the purpose of ionizing the air between the plates. Many precautions were taken to prevent various disturbances. For instance, the light from the arc lamp had to pass through certain materials before it entered the experimental chamber so as to rob it of its heat. The air in the chamber had been made dust-free by passing it through glass wool. A large cylinder surrounded the entire apparatus and was filled with oil which was kept at a constant temperature. There were the necessary instruments to measure the pressure of the air in the chamber and to measure with a high degree of accuracy the voltage applied to the plates. For the recording of the time of travel of the droplet a printing chronograph was used which would record that time to the one-hundredth part of a second.

The diagram shows how there is a large space above the two plates. It was in this space that the droplet was made by simply blowing a puff of air from an atomizer over some oil. The atomizer itself was outside the space and the air used by it was first made

dust-free. Of course, a great many droplets were made at one time, but they were all outside the space between the plates. There was a small opening in the center of the upper plate through which, occasionally, a drop would float. As soon as such a droplet came between the plates the observations would begin.

The friction caused by the atomizer would electrify the droplets which, by the way, were generally of a diameter of about one twenty-five-thousandth of an inch. That they were electrified could easily be shown. While they were on their downward path between the plates the current was switched on and the droplet would then be attracted to the upper plate and reverse its motion. When the air in the chamber was ionized, some ion or electron would occasionally meet the droplet and attach itself to it, which was easily seen by the fact that it would change its speed under the attraction of the electric field of the plates. By observing thousands of such changes a very reliable record could be made of the history of a droplet when it captured one or more electrons. There was a certain amount of difference of time of travel between the cross hairs for the capture of a definite number of electrons, and there was one certain amount below which this difference never went. This showed conclusively that there was only one electron captured. Calculation of a very simple kind showed further that the other observed differences of time corresponded exactly with what one would expect if two, three, or more electrons were captured.

Knowing the strength of the electric field between the plates, it was a relatively simple matter to calculate the strength of the charge on the droplet and thus the charge on a single electron. I mentioned some time ago in what simple manner the ratio was found be-

tween the mass of an electron and its electrical charge, and now, as we have found the amount of this charge we can figure the mass of the electron. I would like to give the results of these experiments and calculations, but the numerical results look formidable on account of the long string of ciphers before we come to something more substantial. On the other hand, it is always easy to skip a few lines, and though ciphers are only appreciated at the rear end of the statement of one's assets or fortune, yet I know of no case where they have done anyone harm. As an illustration I give here the mass of an atom of hydrogen. It will probably keep many readers from asking for more, and it may please a few who delight in statistics. One atom weighs

$$0.000,000,000,000,000,000,000,000,662 \text{ grams.}$$

The physicist has a much better way of writing these impossibly small fractions. He would write the above fraction thus:

$$0.662 \times 10^{-24}$$

In whatever way we try to express such small quantities—whether we do it by the use of a large number of ciphers or by the method used by scientists —we fail utterly to get a mental picture of the amount, and so some writers have tried to give a more concrete idea of sizes and numbers by illustrations, somewhat like the one mentioned just now, referring to the number of electrons in the amount of electricity flowing through a sixteen-candle-power lamp in one second. However, such illustrations have never given me a real picture of the thing they were supposed to illustrate, and I doubt if they have done more for others. Nevertheless, they are enlightening in a way, because they bring to our minds in a most forcible way the impossibility of grasping the meaning of the

figure given, and they compel us to be satisfied with proportions instead of actual sizes, and this is what we should always do if we want to get a clear idea of the relation of things.

It is, of course, just as impossible to imagine all the inhabitants of Chicago counting electrons for the next twenty thousand years as it is to digest a figure with twenty-three ciphers, but the illustration will keep you from worrying when, somewhat later, you read that in some process of nature a few billions of electrons are emitted from a body every second. You will have learned to say: what is a few billions more or less when we have such quantities to draw on? Incidentally, Millikan's illustration brings out a fact about Chicago which should be of interest to prospective settlers in that city. According to the price of current required to run a sixteen-candle-power lamp for one second, the happy Chicagoans pay only 1.8 cent per kilowatt hour for their current.

Now that I am on the subject of illustrations, I might give another one, originated by Sir Oliver Lodge, who said that if you want to get an idea of the number of atoms in a drop of water (size of drop not mentioned) just imagine the entire earth with all that there is on or in it made up of baseballs. The number of baseballs would be about equal to the number of atoms in that drop. I confess that this illustration does not help me much in forming an exact picture of the amount, but it does something else for me, which is perhaps even better. Now when I read about the large number of atoms of helium emitted by a small piece of radium every second, I imagine that I take a few billions of baseballs out of the earth and try to think how much of a gap this would make. I see right away that the earth has not suffered as much as it does when a new subway is dug in New York, and I quit worrying about the fate

of the piece of radium. You see again that it is proportion—percentage—that counts, and not the actual amount.

It is percentage that counts in all our observations. Let me illustrate. I bandage your eyes and give you a ten-pound chunk of lead in your hand. I take it away and now give you another piece of lead weighing ten pounds and one ounce. I ask you which piece was the heavier and you answer that you do not know, that there seemed to be no difference at all. I then give you first a one-ounce piece of wood and then a two-ounce piece, and again I ask you which piece is the heavier, and this time, without hesitation, you say that the second piece was much heavier. And yet, in either case, that difference was one ounce. The difference was this: that in the first case I had added one ounce to ten pounds—that is, one in a hundred and sixty—or five-eighths of one per cent; and in the second case I had added one ounce to one ounce, or a hundred per cent. If I had added ten pounds instead of one ounce in the first experiment you would not have hesitated. You can distinguish a hundred per cent in weight but not such a small amount as five-eighths of one per cent.

If you can say with some degree of assurance which piece is heavier when the difference is, say, two per cent on a total of ten pounds, you will find that you need also a difference of two per cent if the total is twenty pounds or one pound or one ounce. Two per cent is the measure of your sensitiveness as to weight. Somebody else may be more or less sensitive than that. Your sensitiveness as to other things may be different. You may be very sensitive as to the intensity of light or sound, but not sensitive at all as to differences in the amount of sweetness or sourness of things you eat. A skilled musician may be extremely sensitive as to the number of vibrations per second of the notes he

hears, but it is always in percentages. One or two more vibrations on the lowest note of the piano would be readily perceived by him, because this makes a large percentage of difference, but one or two vibrations more or less on the highest note might be unnoticed by him. Various persons have various combinations of sensitiveness, which makes one more adapted to this and another to that pursuit. In this, and in practically all things of our daily lives, it is percentages that count. An increase of two dollars a week is very acceptable to the man who earns twenty dollars a week, but not to the man whose salary is twenty-five thousand dollars a year. The percentage of increase is ten in the first case and negligible in the second.

The scientist is always after small percentages of error. He does not express his faith in the truth of his conclusions in glowing terms, but in percentages. He will say that his observations are correct to within such-and-such a fraction of one per cent. He realizes that his instruments are not absolutely correct, that the adjustments he made leave something to be desired, notwithstanding the care he took, and, most of all, he knows that he himself is a human being with all its limitations. He depends, therefore, on the fact that he is not apt to make the same mistake a great number of times in succession, and so he makes a great number of observations and estimates the probable error by applying mathematics to the law of chance.

CHAPTER X

Gambling

As long as human beings had to depend on their senses only for the observation of nature and its laws, knowledge was very imperfect, and odd beliefs and superstitions held the stage. When man learned to make himself instruments with which to observe, and especially with which to measure, he began to learn a great many things which heretofore had been hidden from him; and, more important perhaps, he found that he knew many things which were not so.

Instruments can be made infinitely more sensitive than our senses. It would be a very poor butcher's scale which would not indicate a one-ounce difference on a ten-pound weight. Scales have been made which will show a difference of weight between a piece of paper and the same piece after a pencil scratch has been made on it. Even finer scales than that have been constructed.

As to measuring length, there are devices in existence—devices which are being used in many manufacturing establishments—which will show differences in length of one fifty-thousandth of an inch. There are gage blocks which are guaranteed to be correct within half that amount, and the method of measuring by means of the interference of light permits measurements to be made to within one-tenth of that again.

Nevertheless, we cannot say that our instruments are perfect. What is worse, we shall never be able to make them perfect. As a result, our observations shall always be more or less, but never absolutely, perfect;

and so our final task must be to estimate our own accuracy. Here is where the scientist becomes the gambler. He must depend on the laws of chance.

The laws of chance tell us what is probable, but not what is certain to happen. They do not predict. They do not tell us what *will*, but what *may*, happen.

I take a pack of cards and pick out four of them, one at a time. What chance have I that I'll get four aces? My chance to get an ace the first draw is four in fifty-two, or one in thirteen, for there are four aces and fifty-two cards. There are now fifty-one cards left and only three aces, and so my chance to draw an ace this second time is three in fifty-one or one in seventeen. The chance to draw a third ace is now two in fifty, or one in twenty-five, and the chance to draw the fourth ace is one in forty-nine. Therefore, my chance to draw four aces in succession is $\frac{1}{13} \times \frac{1}{17} \times \frac{1}{25} \times \frac{1}{49} = 1/270{,}725$.

This does not mean that I am sure to get these four aces in succession if I should play this little game 270,725 times. It might not happen if I played it ten times as often. On the other hand, it might happen every time I try it. This latter is *possible*, but not *probable*. The laws of chance give us the probability, but say nothing of the possibility.

You might ask what the scientist has to do with such a law which cannot possibly tell us anything with certainty. Well, the fact is that these laws tell us more than the mere probability. They tell us what is certain to happen if we keep at it long enough. Perhaps an illustration is in order.

Did you ever play roulette? Well, don't do it. The cards are stacked. The law of chance will tell you this as an absolute certainty. Suppose you put your money on red, what are your chances that you will win? As there are only two colors, red and black, it

is evident that your chances are even—except that once in a while zero turns up, in which case neither red nor black counts. This is the way the honest gambling house stacks the cards. What the dishonest house does in addition is various and nefarious.

Let us forget this zero for a moment and let us think that there are only two possibilities: the little ball drops either on red or on black. Your chances are now even, but this does not mean at all that you are going to win once in every two plays. It may happen that you do not win once in ten successive plays; or, on the other hand, you may win every time. Suppose you win for the first time at the tenth play, then the reality was one in ten, but your mathematical chance was one in two. Now suppose you keep on playing hundreds, thousands of times. You will find that the reality does not correspond to your mathematical chance, but, on the other hand, the ratio between the number of times you won to the number of times you lost has become more and more close to unity. The more times you play, the nearer this ratio comes to the theoretical evenness of chance. There is nothing gradual or regular about this approach to unity, and you should not bet on it; but in the long run reality and probability come very close together, if they do not coincide.

Things in the world of atoms and electrons do not go by the thousands but by the millions and billions and even larger numbers, so that there reality and chance may be expected to be so close together that it would be a waste of time to distinguish between them.

Nevertheless, when the scientist tells you that something must be so and so, because that is the way the laws of chance make it, he is gambling. But so is the life insurance company when it builds its business on the probable length of life of the insured. The

insurance company is safe because it deals with millions of people. If it insured a few only, it would not be safe at all. Where the insurance company deals with millions, nature deals with millions of millions, and knowing this, the scientist feels at least as safe about his results as the best conducted life insurance company.

When we make an observation about some phenomenon, or measure something, we know that our result is not absolutely correct; we know that some little imperfection is somewhere, but we do not know what or how much it is. If we did, we should do it all over again. If we repeat our observations or measurements a hundred times, we still do not dare to say that one of these hundred is perfectly correct, but we are a little surer than we were when we made only one. It is very unlikely that the true result lies above the maximum or below the minimum of our observations. It is highly probable that it is somewhere between, but just where is still hidden from us.

Here is where the mathematics of the laws of chance come to help us. The method used by the scientist to find the probable exact truth is what he calls "the method of least squares." It is this: He imagines that he has already found the correct answer, and then he takes the differences between this correct answer and all the various amounts he has found for his observations. He squares all of these differences and adds them together. The trouble is that he never had the correct answer and therefore could not take these differences, and so he calls that correct answer X, and when he has added all the squares of X-A, X-B, X-C, etc. (A, B, C are supposed to be the figures which he has found from his observations), he calculates X for the condition that the sum of all these squares shall be a minimum.

Suppose I had made a hundred observations and suppose they were all perfectly right; then I could plot the results on a piece of section paper and they would, of course, all fall on a straight horizontal line. As a matter of fact, however, the results of a hundred observations are never all perfect and never all the same, so that, if I should plot them, they would not all come on a straight line. Some points would be above the ideal line and other points would be below. The trouble is that we do not know where this ideal line is. If, for instance, we had two data, expressed by points on the section paper, and if one were five and the other seven squares above the base line, it would be easy enough to find where the ideal line would be. It would be at six; for if we take the distances from our two points to the line six we find one for each: that is to say, one point is a distance *one* above, and the other a distance *one* below, the line. The sum of the squares of these two distances is two, and this sum is smaller than if I should have placed the ideal line elsewhere. If I should have it placed one-half division below the high point and one and a half divisions above the low one the sum of the squares would have been two and a half instead of two.

To figure out where the ideal line comes when we have a great many observations is quite some work, and I doubt whether it was ever enjoyed by anybody; but when it is done then we know that we have made the best possible guess.

When we deal with materials as they appear in nature we are really dealing with a great many individual particles, some of which may be doing this and others that. It would be impossible to examine individual atoms or molecules, and the scientist expresses this by saying that he deals with a statistical average. Here again he depends on the laws of chance. He applies

these laws to the movement of molecules and arrives at some of the most important results as to the qualities of gases.

The molecules of all bodies are supposed to be in everlasting motion and sometimes commotion. The amount of motion depends on the temperature. The motion is more rapid at high than at low temperature and it is supposed that there may be a state when there is no motion of the molecules at all; at that point we are supposed to have reached the absolute zero. Liquid hydrogen has a temperature not many degrees removed from this absolute zero; liquid helium comes still nearer to it, and solid helium still nearer, but so far no one has been able to reduce temperature to the absolute zero, and it is not likely that it ever will be done.

The molecules of a solid body are supposed to vibrate, but nobody has ever seen them do it. There is, however, plenty of circumstantial evidence to make us feel fairly sure on this point. There is, for instance, the fact that solid bodies expand when heated. This may be due to the fact that the molecules of the body have taken new positions, somewhat further away from each other, or it may be due to an enlarged swing of their vibrations, which, after all, would also compel them to assume new positions. Altogether, we can make out a fair but not a very strong argument in the case of solid bodies, but when we consider fluids, whether gaseous or liquid, we have much more evidence and of a more convincing nature.

A few simple experiments show us quite conclusively that the particles of liquids and gases must be in motion. Pour some water in a glass and, very cautiously, pour some colored alcohol on top. If you are a little skillful, and have steady nerves, you can do this so that the alcohol lies on top without having been

mixed with the water. Let the glass stand for some time, and when you return to it you will find water and alcohol a perfect mixture. Of course, you might have expected this result if the heavier of the two liquids had been on top, but this was not the case; quite the opposite was true. The only reasonable explanation for the fact that some of the lighter material has gone down and some of the heavier has gone up is that the particles of both liquids had some movement which allowed them to go against the attraction of gravity.

A similar experiment can be carried out with gases. It is a classical experiment, even more convincing than the previous one. Two glass globes are filled with gas, one with carbon dioxide (carbonic acid) and the other with hydrogen. Each globe has a brass tube fitted to it, which is provided with a cock so that the globe can be kept closed after filling. The two brass tubes are screwed together, after which the globes are set in a holder in such a manner that the one with the hydrogen is on top. The cocks are now opened and the apparatus is left standing. After a sufficient length of time has lapsed, the contents of the two globes are examined and it is found that both globes contain a mixture of hydrogen and carbonic acid. Now, this would not have been strange at all if the carbonic acid had been in the top globe, for we all know that a heavier gas will fall and displace a lighter one and carbonic acid is many times heavier than hydrogen. But the opposite was the case here. The only reasonable explanation is again that the particles of the two gases had some kind of movement which allowed them to wander into the neighbor's apartment.

Then there is still another experiment which allows us actually to see the movement of molecules, or rather the result when a moving molecule collides with a very small piece of something or other which is floating in

the liquid or gas and which can be kept under observation under a microscope. This is the experiment of the Brownian movements.

The phenomenon of the Brownian movements was first discovered by Brown, an English botanist, as early as 1827, but its meaning was not understood until many years later. Brown noticed that small particles, floating in a liquid, were describing irregular, wiggling motions as if they were alive, and he drew the conclusion that they were probably endowed with something similar to life. It is now considered as the result of a kind of hazing game on the part of the molecules of the liquid. All these molecules are in motion and one of them strikes the small particle and pushes it on in the direction in which it was going. This brings the particle in the path of some other molecule, which gives it another shove in some other direction, and so on. The molecules themselves are going at such a terrific speed that it would not be possible to follow their motion and, besides, they would be too small to be seen even with the very best microscopes, but when one strikes the small particle it must move an object many times heavier than itself, and as a result it gives that particle a very much lower speed. Hang a ten-pound piece of lead from a string, take a small pebble and throw it with as high a speed as you can against the lead and you will see the lead move, but with a very much lower speed than the pebble.

Being convinced that the molecules of a gas or a liquid actually move, the scientist set to work to apply mathematics in order to find out what must be the result of such movements. He had a very complicated problem to deal with. Here was an enormous number, and also an unknown number, of little objects moving hither and thither, in all possible directions and with

an unknown speed. The problem he set himself to solve was, what would the effect of such movement on the particles of gas themselves be and what on the walls of the container; and further, what would be the speed of the molecules at a given temperature, and how far could they move before they must strike some other molecule? A nice little problem to solve.

As a matter of fact, he did not try to solve the problem for some individual molecule, but he tried to find the *statistical average.*

The results he obtained were of the greatest possible interest. He even obtained a value for the probable size of an individual molecule, and later experiments and calculations of an entirely different nature have shown that he was as nearly right in his results as could be reasonably expected. One of the main instruments he employed in his analysis was the law of chance, and he could employ it because he was dealing with such enormous quantities that there was no longer much of what might be called *chance*, but practical certainty. All the various things that could happen must have happened in equal amounts.

We now have this picture of the behavior of molecules in solid bodies, in liquids and in gases:

In a solid body the molecules are in constant vibration and the amplitude of these vibrations depends on the temperature. However great this amplitude may be, it is never great enough to bring a molecule out of range of the attraction of other molecules. It cannot get away, that is, so long as it is part of a solid body. If we keep on increasing the temperature, there comes a time when the amplitude is so great that some of the molecules get out of the range of this attraction and are free to move on in the direction they had at the moment when they escaped their bonds.

It almost seems as if I am contradicting myself here, for I said first that they cannot escape and now I say that they are escaping. However, I said also that they cannot get away so long as they are the molecules of a solid body, and, when the molecules get away from each other's attraction, the body is no longer solid; it has become a liquid.

This is the difference between a solid body and a liquid, that in a solid body the molecules move in paths which are restricted by the other molecules, while in a liquid these paths are only restricted by some outside resistance—such as the walls of the vessel in which it is contained, or, perhaps, some other thing. When I say that the path of a molecule of liquid is not restricted, I do not mean that it never meets an obstruction until it reaches the walls of the vessel, for it may and does collide with other molecules which happen to cross its way, but that it is free to leave its neighbors and follow a course of its own.

There are other things besides the walls of the vessel which keep the molecules of a liquid from going on their way, never to return. For instance, there was the colored alcohol on top of the water which kept the water molecules from escaping into the air. These molecules had motions in every imaginable direction. Some were going in a direction which would bring them out of the mass of liquid if there were nothing to stop them. What stopped them was the layer of alcohol, but it did not stop them altogether. A few molecules would penetrate into the alcohol and would go on until they collided with some other molecule. Similarly some molecules of alcohol penetrated into the water. We say that the water and the alcohol have mixed. No better proof is required for the truth of the idea that these liquids are composed

of very small particles which are moving under the influence of something or other.

The molecules of a solid body are packed close together. Those of a liquid are about as close together, sometimes a little further apart, sometimes even a little closer. There is, for instance, the well-known example of water and ice. If the molecules of water were not closer together than those of ice, ice would not float on water, for it would be heavier. By the way, have you ever thought what this world would be if ice were heavier than water? This earth would be an entirely different world and we would not be here to philosophize about it.

You might ask what it is that prevents the molecules of water in an open vessel from escaping at the top, for there is nothing but air above it. Well, this air is almost enough. Almost, but not quite. Water evaporates, which is merely a short way of saying that some of its molecules escape. Your next question is naturally, "And why don't they all escape?" Well, so they do; give them time. You must remember that these molecules are traveling in every imaginable direction. Only a small portion is going straight upward at any given moment. The rest is going downward or sidewise or at some angle. Some will jump out of the mass of water, straight up, collide with a molecule of air and come straight down again. Others shoot out at an angle and either escape or collide with the air and are turned back, much as a billiard ball is deflected when it strikes another one at an angle.

If the air above the vessel with water is dense, then there is much chance for collisions between escaping molecules of water and molecules of air, so that evaporation is slow. If the water is cold, the speed of its molecules is so low that the chance for escape is small. Again evaporation is slow. We get the most

rapid evaporation when the temperature of the water is high and the air pressure low. There is a standard experiment which illustrates this very prettily. A flagon of water is set over a flame to boil. The flagon is connected to an air-pump. We exhaust the air, and presently the water boils. We keep the air-pump working and draw the steam away as soon as it is formed; in other words, we maintain a vacuum over the water. Meanwhile, as soon as boiling starts, we remove the flame. Nevertheless, the water keeps on boiling, though the temperature in the bottle is now far below that of ordinary boiling water. Keeping the pump at work the water boils on until—suddenly—the entire mass of water congeals. You see from this that water can boil at any temperature above the freezing point, provided that it is not hampered by too much air pressure.

You may be worrying by this time about the fact that this jumping out of the molecules is a very haphazard affair; that a lot of it may be going on between nine and ten in the morning but very little between ten and eleven; that it is something without system or regularity. One moment all molecules may be going crosswise and the next they may be jumping out. For an answer I refer you to the number of baseballs required to make this earth, which is, according to so good an authority as Sir Oliver Lodge, about the same as the number of atoms in a drop of water. It is true we are dealing here with molecules and not with atoms, but there are only three atoms in a molecule of water, so that all you have to do is to divide the number of baseballs by three. You'll find the quotient still a very respectable number. Everything is going on at the same time; somewhat more of this thing here, somewhat less of the same thing there. Here is where the scientist applies his laws of chance and his statisti-

cal average and the results—the things we experience in our daily life—bear him out.

The molecules of a gas do the same as those of a liquid, but on a more liberal scale. They are so much farther apart that they can travel much longer distances without danger of colliding with another traveler. They do collide, however, and, of course, they must ultimately strike the wall of the container. Now, a very natural question is: don't they finally come to rest? We like to imagine these collisions between the molecules themselves or between the molecules and the wall as being of the nature of the rebound of a rubber ball. It may rebound a few times, but the height to which it rises becomes less with each rebound and finally it remains on the ground. Why do the molecules of a gas keep on moving?

Throw a piece of lead on a lump of clay and there is no rebound—at least not enough to be perceptible. Drop a billiard ball on a marble slab and the ball rebounds almost to the height from which it was dropped. Lead and clay are not elastic, ivory and marble are elastic to a high degree, especially ivory. An interesting experiment, which anyone who has a pair of ivory balls can make, is to hang these balls so that they come to the same level and close together. Pull one of the balls a little distance away from the other and release it. It strikes the other ball and, as a result, it remains now at rest while the other ball swings away with practically the same speed with which the first ball struck it. The second ball returns, strikes the first ball, remains itself at rest and sets the first ball going. This play is repeated a number of times, but you will notice that the amount of swing gradually decreases, and finally the balls stop swinging. Ivory is very elastic, but not perfectly so. If it were perfectly elastic, it would give all its energy to the

object which it strikes (provided, of course, that it has the same mass) and the play would go on forever. It would really not go on forever in our experiment, for the balls lose some of their energy overcoming the resistance of the air and by the work required to bend the strings from which they hang.

Molecules are perfectly elastic. They can go on forever striking other molecules without losing any part of their energy. The collisions which take place may start them on another course, or even turn them back, but they go on with the same amount of energy as before the collision, and therefore with the same speed.

This is all very well when one molecule meets another, but what about it when it strikes the walls of the vessel? Molecules may be perfectly elastic, but the walls are certainly not. The point is well taken and deserves an answer. Every time a molecule of gas strikes the imperfectly elastic wall, it loses a little of its energy. By and by the gas would lose all of its energy if it were not that this energy is being replenished all the time. The molecules of gas have energy because they are in motion and they are in motion because they are warm. If they were at the temperature of absolute zero they would have no motion. They would not form a gas but a solid body. The energy of the molecules of a gas is the energy of the heat they carry. When they strike the wall of the vessel, they lose a little of their energy, which means that they lose a little of their heat; in other words, the gas would get a little colder if it were not that a corresponding amount of heat is immediately supplied by the surroundings. If, however, the surroundings are colder than the gas, then the gas will lose some of its energy and we can see this by the fact that the pressure of the gas is being reduced. This

goes on until gas and surroundings have come to the same level of temperature. From that moment on, gas and surroundings go together.

The foregoing shows us how temperature, volume and pressure of a gas are related. If we confine a certain volume of gas in a closed vessel and heat it, we give more speed to the molecules of the gas, thus increase their energy, and cause them to strike the walls heavier and more blows. We say that the pressure is increased. If we pump a double quantity of the gas into the vessel we will have twice as many molecules to strike the walls in the same amount of time and again we say that the pressure is increased.

The important thing to keep in mind is that gas has no energy of its own but only that which was supplied to it by heat. Heat is a form of energy and gas is merely the carrier of that energy, but not its source.

CHAPTER XI

The Market of the Universe

THERE is a constant trading going on in nature. No one seems to be satisfied with what he has. Everything must be exchanged for something else. The sun sends down some heat and light and ultra-violet rays and other vibrations, and the plant grabs them and changes them into chemical reactions and makes some new stuff and sends it down to the roots, where it is made over into something else again. By and by, when energized by some more sun-heat, the oxygen of the air—no longer satisfied with being merely that—changes the plant into a number of other things and leaves a residue—carbon. Not knowing what the other things are or what becomes of them, I shall follow only that carbon. Another product of sunlight, a human being this time, digs it up and shovels it into a furnace and, by some tricks of his own, compels the oxygen of the air to do what it has neglected so far: to make something else of that carbon. The human being is not interested in what was concocted out of that carbon, but uses a by-product, heat. He transfers that heat to water and causes pressure to develop. He changes the pressure to motion behind a piston, or at the blades of a turbine wheel, and then he takes this motion and makes electricity out of it. As he does not want electricity at all, but something entirely different, he leads it to the place where he wishes to use it and transforms it into heat or light. The heat may be transformed somewhere else into chemical

action, or he may do the same thing with light and get a photograph.

I have introduced the human agency, but it was not at all necessary. The same things would have taken place without him, but perhaps not so rapidly and certainly not in such an orderly fashion. However, there is one thing in all this trading and changing of which we can be absolutely sure: there is no cheating. All deals are on the square. There is a fixed rate of exchange from electricity to heat, or from heat to mechanical power, or from light to chemical action. There is no short changing or shortage of goods. On the other hand, nature is very careless about the packing and delivering. It is sometimes exceedingly difficult for us to locate the goods, and they are by no means packed in readily recognizable packages. What is worse, when we ask nature to change something we have into something we need, she will do so but she makes certain stipulations from which she will not deviate. For instance, when we wish to change the mechanical power of the steam engine into electricity, nature obliges us but stipulates that we shall not get the entire amount due us as electricity, but that we must accept a certain percentage in heat, something for which we have no use just then. Not only do we not want that heat but it is actually a nuisance at the dynamo. However, nature insists and we must accept her terms. This is not all. We wish to use the electricity at some other place and nature has provided the means for us to do so. She has made some substances conductors, but she levies a charge for the use of her means of transportation. When we measure the amount of electricity we get at the receiving end, we find that it is not quite so much as was delivered by the dynamo. We are in the habit of saying that a certain percentage is lost, but this expression is not

correct. Nothing was lost, but part of the resulting products were of no use to us at that moment.

It used to be thought that there was a real loss, and it is not so very long since we have learned that nothing gets lost in nature. There is a complete and honest exchange, but nature has a bad habit of throwing to the four winds some of the things she gives us in exchange for what we offer her, and it is often very difficult to find some portion of our bargain.

That there was such a thing as the conversion of one kind of energy into another was believed by many philosophers, but they could not prove it. Some of them propounded the idea that in such a conversion nothing was lost. This was the dogma of the *conservation of energy*. However, it was not until the Englishman, Joule, carried out his classical experiment about the conversion of heat into mechanical power, and vice versa, that this dogma became one of the accepted theories in science. He measured a certain amount of mechanical power, converted it into heat, and then measured the amount of that heat.

One of the things necessary for the measuring of anything is some unit of measurement, and, if we want to be understood by others when we talk about the subject of our measurements, there must be a common understanding, an agreement, as to what units shall be used. The units used by Joule were the foot-pound and the calory. The foot-pound is the amount of work done when one pound is lifted one foot, and the calory is the amount of heat required to heat one kilogram of water one degree centigrade. Among the English-speaking nations another unit is used to express the amount of heat, namely, the British thermal unit, or, as it is commonly called, the B. T. U.

It is not difficult to produce the conditions which will give exactly one foot-pound, for it is easy to

measure a foot with great accuracy, and, similarly, it is easy to weigh one pound. However, when it comes to showing just how much a B. T. U. is, we are up against a somewhat more difficult proposition. A B. T. U. is the amount required to raise one pound of water one degree Fahrenheit. This seems to be easy enough, but there are a few conditions attached to the foregoing definition, which makes it necessary to exercise considerable care. The water must be pure water, the experiment must be made when the barometer reads 760 mm., and the reading of the temperature must be at a certain given point. You see, the amount of heat required to raise the temperature is not the same for high and low barometer readings, nor is it the same whether we raise it from forty to forty-one, or from a hundred and forty to a hundred and forty-one. If other conditions prevail when the test is made, then the necessary corrections must be made in the result.

Perhaps somebody has asked the question why it should be water, or, for that matter, any other specific substance. Why not say that one pound of material must be raised one degree? The answer is that it takes various amounts of heat to raise various substances the same number of degrees. The amount of heat which will raise a pound of water one degree will raise one pound of iron almost eight degrees. We express this by saying that, if the specific heat of water is one, the specific heat of iron is about one-eighth. I would like to express myself a little more precisely than to say that iron has a specific heat of *about* one-eighth, but if I should do this I would have to give a tabulation for the specific heat changes with the temperature. For instance, the specific heat of iron when at a temperature of 600 degrees is 0.127, but at a temperature of 2500 degrees it is 0.167, or 31 per cent higher.

If I should take a pound of water at 100 degrees and add to it a pound at 50 degrees, I would get two pounds at 75 degrees. I would have cooled the warmer water by 25 degrees; but I would have to add almost eight pounds of iron, also at 50 degrees, to cool the water the same number of degrees.

Joule carried out his famous experiment by causing a paddle to revolve in a quantity of water. The paddle was moved by a weight attached to a rope which ran over a pulley. The product of the number of pounds of the weight and the distance it was allowed to fall gave him the number of foot-pounds. The paddle, stirring the water, caused it to rise in temperature. This rise was easily measured by a thermometer inserted in the water. Of course, this is only a rough description of the principle of this very refined test. Many things had to be done to avoid the loss of some of the heat generated, but these things are not of as much interest to us as the fact that he found that there is a definite and constant relation between the number of foot-pounds and the number of degrees rise in temperature. He found that 777 foot-pounds are required to raise one pound of water one degree Fahrenheit. This is called the *Mechanical Equivalent* of heat. It has since been determined many times and with greater and greater accuracy, because it is of the greatest importance in engineering.

The interesting aspect of this mechanical equivalent is that it takes so many foot-pounds to generate so little heat; or, what is a more cheerful way of saying the same thing, that it takes so little heat to get so many foot-pounds of energy. In fact, we may consider this as one of our greatest blessings. If this mechanical equivalent were one instead of 777, it would mean that we would need 777 times as much coal as we are using now to run our steam engines and such

things as locomotives or ocean liners would be out of the question.

One pound of anthracite coal gives about 12,000 B. T. U's when it is burned and this would be sufficient to raise 12,000 pounds to a height of 777 feet. That is, it could do this if there were no losses. Unfortunately for us the losses are very great in this instance. It is one of the great problems of engineering to keep these losses down to a minimum. There are losses all along the line, and some occur as soon as we begin to burn the fuel. We burn the coal in a furnace and cause the necessary draft, either by a tall chimney or by blowing air through the fuel; but in either case the gases which escape are hot and carry with them some of the heat value of the coal. Coal is mostly carbon with a certain percentage of hydrogen. Twelve pounds of carbon need thirty-two pounds of oxygen for perfect combustion, so that there is formed forty-four pounds of hot gases. Most of the heat of these gases is usefully employed by heating the water in the steam boiler; but, when the gases go out of the chimney, they must be at least as hot as the water in the boiler and generally very much hotter. And so, forty-four pounds of heated gas escape without doing anything useful.

But this is only part of the story. The oxygen needed for combustion is part of our atmosphere, and when the coal needs some oxygen in order to burn, it must invite all the other constituents of the air to the feast. There is about four times as much nitrogen as oxygen in the air, so that there is another one hundred and twenty-eight pounds of gas to be heated. Altogether, one hundred and seventy-two pounds of heated gases escape through the chimney or are blown out in some other way when we burn twelve pounds of carbon. As to the burning of the hydrogen in the coal, this is even worse, for twelve pounds of hydrogen need ninety-six

pounds of oxygen and, therefore, four hundred and eighty pounds of air.

This is only one of the ways in which nature levies taxes for the use of her materials, and it is not the worst one. The heat we have generated in the furnace is to be used to make steam in the boiler. Let us see what taxes she demands for this conversion of heat into pressure, or power, as you will. Suppose we start with water in the boiler at a temperature of sixty-two degrees. The first thing the heat in the furnace does is to raise the temperature of the water, and it keeps on doing this until the temperature reaches the boiling point of water, which is, under ordinary circumstances, two hundred and twelve degrees. From now on, the water does not get hotter but is converted into steam by the further application of heat. To raise one pound of water to the boiling point required one hundred and fifty B. T. U's, but now to make out of this pound of hot water a pound of steam, almost one thousand B. T. U's more will be required, and then we have only steam at the pressure of the atmosphere, so that we have to spend still more heat before we can use this steam for the generation of power.

When we use this steam in a steam engine we'll find that still other taxes have to be paid, for we cannot allow the steam to become water again while it is in the cylinder of the engine; it must go out as steam. And then, there is the unavoidable friction which takes its share of the power. The combustion engineer does all he can to make as much steam with as little coal as possible, and the mechanical engineer does his level best to make as much power as possible with the least amount of steam, but when both have done all that is humanly possible, we find that, after all, nature has taken about seventy-five per cent as her share, leaving us the rest.

What nature does with her share would not interest us if it were not that she often uses it to make further trouble for us. Take for instance the tax which we will call frictional losses; not satisfied with reducing our income, she uses this friction to wear down our machines, compels us to use oil and much care, and makes us spend a great deal of time, money and gray-matter in the design and repair of the machine.

However, much as we may regret that nature does not allow us to use for our own benefit all of the heat stored up in that pound of coal, or all of the power stored up in the steam we have made, we must acknowledge after all that nothing was lost. All of the coal is still there, though in a form not immediately useful to us. The carbon has been hidden in the carbonic acid, which is one of the products of combustion, and may appear later on as part of the spinach at our dinner table. All of the energy also is still in existence, though we may not be able to use it in a way which we would like at the moment. Neither material nor energy can be destroyed. This is a law of nature, which had been hinted at by some philosophers centuries ago, but which did not become a recognized law of nature until the middle of the nineteenth century. It is now so well established that we no longer question it. We take it for granted; we swear by it; and, if we see something which seems to contradict it, we say right away that something in the process must have escaped us but that the law holds good.

The law says that there is a certain amount of matter in the universe which may appear in different forms, but which cannot be increased or diminished and, further, that the same applies to the total amount of energy. This energy may manifest itself as momentum of bodies in motion, or as heat (which is molecules in motion), or as electricity, or light, or what not, but

nothing is ever lost and nothing can be added to it. The two entities, matter and energy, are all there is in this world. This view of nature has helped wonderfully to clear up many things which formerly seemed dark, and has led to a better understanding of the working of nature; it was one of the biggest and most broadening conceptions presented to us by science—but, it has had its day, and though not discarded, it had to be modified because of new knowledge.

CHAPTER XII

A Modern "Widow's Cruse"

EVERYBODY knows about radium, but not everybody knows that the little bit of it now existing in the world has completely upset many of the ideas which we had and which were the results of many years of painstaking experimentation and thought by the greatest scientists of this and other ages. Radium will give off heat constantly, year after year. All of the materials with which we were familiar could give off heat when they were hotter than their surroundings, but gradually they would cool down in consequence, and they would cease to give heat as soon as they had reached the temperature of their neighbors. It was merely a transfer of heat, or energy, from one body to another. There was nothing to worry about. It was all correct and in accord with the law of the conservation of energy. But radium gives off heat and remains at a temperature above its surroundings, and this does not fit the law at all. We seem to have here a perpetual motion scheme against which we have been warned by all scientists and engineers of good standing.

A pound of radium, if there is such a quantity, will melt two pounds of ice every hour, and do it all the time. It takes, roughly speaking, eighty B. T. U's to reduce a pound of ice to a pound of water. We then have water of the same temperature as the ice was. Of course, I am speaking of ice which is about to melt, and not of ice which is below freezing temperature. These eighty B. T. U's are needed to give the molecules of ice that freedom of motion which is the characteristic

of a liquid. Another quantity of heat, and a much greater one, is required to convert water of a temperature of two hundred and twelve degrees into vapor or steam of the same temperature. This is called the latent heat of water, and is one of the reasons why we have to apply so much heat to the water in the steam boiler and why we get so little power out of the heat. This is very annoying, but, on the other hand, there are compensations. When the cold wind which comes to visit us from the polar regions strikes the water vapor in the air, it makes the rain, and, in so doing, it loses much of its frigidity; for the vapor gives up just as much heat when it is reduced to water as it would require if water were converted into vapor. The vapor in the atmosphere is a great reservoir of heat and it serves us by reducing coldness; while, on the other hand, when it is being formed, it reduces otherwise unbearable heat.

To come back to radium. The 160 B. T. U's which that pound of radium furnishes every hour are enough to give 160×777 foot-pounds of power every hour, or 2070 foot-pounds per minute. This is about one-sixteenth of a horse power, for a horse power is equivalent to 33,000 foot-pounds per minute. The thing for each of us to do is to buy sixteen pounds of radium and let it furnish us for all time to come with all the power we need in our homes. Unfortunately, the present price of radium is somewhat too high for us to put this otherwise excellent scheme into effect. Then, there is another objection, though not quite so serious. When I said that radium keeps on giving this power I told somewhat more than the truth. The power of radium to give out heat diminishes with age. At the end of eighteen hundred years its power is reduced to just one-half what it was at the start. However, as none of us expects to live that

long, the price is a much more serious deterrent than this gradual loss of power.

Where does this power come from? Must we scrap our law of conservation of energy? And then, there is this: at the end of the eighteen hundred years we shall find that not only is the power of the piece of radium reduced to one-half what it was, but the piece itself is reduced in weight. What has become of the lost part? Has the lost material been converted into energy? All these questions were asked by scientists when they first made the acquaintance of this strange material and its strange ways. All these questions have been answered satisfactorily since then. We still have our law of conservation of energy and of the indestructability of matter, except—but this is another story which must be told later.

It has been found that radium throws out pieces of itself—explodes partially, so to say—but what it throws out is not radium. There would not be anything remarkable about this emission of particles if these particles were of the same nature as the piece of radium itself. Any substance which we can notice by the sense of smell throws off some particles. Water, or many another liquid, for that matter, constantly throws some molecules into the air; it evaporates, and, though it might seem at first that what has been released from the body of water is another substance—vapor—yet we know that after all it is merely the same water in another form. With radium it is different. What is thrown off is not radium and cannot be made into radium again. What has happened here is not that the piece of radium has let go some of its molecules or atoms, but that some of its atoms have exploded and have become new substances.

Before saying more about the qualities of this remarkable material, let me tell some of its history.

It was known for many years that the metal uranium had the power to make various substances phosphorescent. The word phosphorescence has more than one meaning. We speak of a phosphorescent sea, and some of us have seen phosphorescent decaying wood, not to mention the fact that the element phosphor glows when seen in a dark place. These things are not the phosphorescence I have in mind. Phosphor glows because it combines with the oxygen of the air, a slow burning process. The same is true of decaying wood; and the phosphorescence of the sea is caused by a multitude of small animals. The phosphorescence caused by uranium is of a different nature. If a Crookes tube is made of glass in which some uranium is present, we shall notice the same phenomena which we would see in any other Crookes tube; but in addition we shall find that the glass of the tube retains a glow for a long time after the current has been turned off.

This experiment was one of the standard ones in the lecture room. Professor Becquerel showed this phenomenon to his classes, as well as another one which was even more striking. After a piece of uranium had been exposed to the sunlight, it seems to have absorbed some of that light and can give it out again. It can affect a photographic plate. One day, while preparing for a demonstration of this quality of uranium, he found that the sun was too obscured to expose the uranium with any chance of success, and so he wrapped it up and placed it in a drawer and, as it happened, on top of a photographic plate, still covered with black paper. He forgot all about it until a few weeks later. Most people would have gone on with the job on hand, but Becquerel had the curiosity complex, which is one of the main ingredients of a scientific mind. To find again the well-known piece

of uranium reposing on the equally well-known sensitive plate would not have aroused curiosity in the average man, but the professor thought that it might be interesting to find out if the one had had any effect on the other. He developed the plate and found that the uranium had made a picture of itself while lying in the dark drawer—without first having been exposed to the sunlight.

This was the beginning of a campaign of intense study of the properties of uranium. Many interesting things were found, but perhaps the most interesting of all was the fact that it had some electrical properties of its own. It was found to have the power to discharge the electroscope when brought near it. (You will remember, the electroscope is that little instrument with the two pieces of gold leaf.) This was sufficiently remarkable, but what was stranger yet was the fact that the ore from which the uranium was derived showed a decidedly greater power to discharge the electroscope than the metal itself. This was the mineral pitchblende, which, at that time, was chiefly mined at Johannisthal in Austria.

Madame and Professor Curie were much interested in this strange behavior of the ore. It seemed to be against all reason that an ore, which might be called a diluted metal, should have the peculiar property of the metal in a higher degree than the metal itself. They came to the conclusion that there must be some other material in the pitchblende which had this quality to a higher degree than uranium and they set out to find what it was. The result was the discovery of radium.

It would take a volume by itself to describe the method they followed to extract the minute amount of radium to be found in pitchblende. Out of a ton of ore about one-hundredth part of a gram of radium

was collected. As if this alone were not enough to make their task difficult, there was still another difficulty to overcome. This was the fact that the metal barium was also present in the ore and this barium is so much like radium in its chemical behavior that it was exceedingly difficult to separate the two. The pure element radium is not used as such. It is always used as a compound either with chlorine or with bromine.

As the process proceeded of separating the radium from the other elements with which it was associated, the power to discharge the electroscope became greater and greater, until finally, when the pure radium was obtained, it proved to be more than a million and a quarter times as strong as uranium. Here we have a a material which gives out heat indefinitely, which affects a photographic plate, and which has the power to ionize a gas and make it conductive. As if this were not enough, it has other properties which are even more striking and which have kept many scientists busy ever since its discovery.

The fact that Professor Becquerel's uranium could make a photograph of itself, although it was separated from the sensitive plate by a thickness of black paper, shows that it was not ordinary light which affected the plate, for even sunlight would not do this. It was some other kind of radiation; a kind which, like X-rays, was able to penetrate opaque objects. Naturally, therefore, many attempts were concentrated on the mystery of these radiations and it was soon found that there were three different kinds emanating from radium. They are called the alpha, beta, and gamma rays. Though having some things in common, the three radiations show enough differences to distinguish them.

Science was already familiar with some radiations besides those of light and heat. It knew of the radiations

sent out by an incandescent wire or by a flame. It knew these radiations to consist of small particles of matter, positively or negatively electrified. The speed of these particles had been ascertained and found to be about ten thousand miles a second. It had also been found that they were heavier than atoms of hydrogen. Other radiations were known, too; for instance, the cathode rays which were found to be electrons. Then, too, the world was familiar with X-rays which seemed to be similar to ordinary light but of much smaller wave length and of much greater penetrating power. When the radiations of radium were examined, it was found that they were just these three kinds of which science already knew.

It would be difficult enough to think of an explanation of why such radiations are sent out by a material which we have excited in some way. It is true that such radiations were observed before, but it had always been under conditions where we had a hand in the setting of the scenery. We had heated a piece of metal, or we had sent an electric current through a vacuum tube; but with radium we had a different set of conditions, in that we had to do nothing. Then, too, the electrons were found to have a much higher speed than had been observed before. The electrons of the Crookes tube had a speed varying from ten to ninety thousand miles a second while those of radium have speed as high as a hundred and eighty thousand miles. The gamma rays, too, were different from X-rays, in so far as they showed a much greater penetrating power. After all, however, these differences were only differences of degree but not of kind; but the fact that radium could produce heat indefinitely was something of an entirely different nature from anything which had been seen before.

It was also noticed that radium would give light and could photograph itself, but this again was not entirely new, for the same thing had been found to be the case with uranium. Strange though it was, it was not something which could be said to stand by itself. However, not long after the discovery of this strange material, it was found to have other attributes which were even stranger than those mentioned before. Professor Becquerel, with the absent-mindedness of which professors seem to have a monopoly, put a glass tube with a tiny amount of the precious stuff carelessly into his pocket and developed a sore which did not heal for several weeks. Professor Curie was guilty of the same carelessness, if I may call it that. His carelessness was deliberate, for he tied a tube with a small quantity of radium to his sleeve and was rewarded by a suppurating sore which did not heal for three months. This was enough to establish the fact that radium had a marked physiological effect. Scientists can be terribly careless with themselves when they want to find out something.

The Curies had other interesting experiences with their pet. The accepted way to test the radio-activity of a material was to bring it in the proximity of the electroscope. This instrument is so much more sensitive than any other known at that time that it will discover quantities which are entirely too small to be found by any other means. The chemical balance will show quantities of material as small as a ten-thousandth part of a gram, but this amount is entirely too large for some of the finer tests. Luckily there is another method which will show the existence of a material, though the quantity may be entirely too small to be weighed. It is the method of spectrum analysis. It is just possible that we may meet this method in our ramblings. This method shows amounts of material

only one-millionth of what could have been found by weighing. As if this is not fine enough, the electroscope will discover an amount of radium one-millionth part of what could have been discovered by the spectroscope.

As the amount of radium the Curies possessed was exceedingly small, the electroscope was their best friend, but they found that it, too, had its faults. It does not specialize on radium, but does its trick when any condition exists in its neighborhood which will ionize the air. Well, they found that the electroscope would be discharged, not only when some radium was brought in its proximity, but that everything in the laboratory had the same effect, even the air, and even their persons. Here was a new property of radium. It had the power to make other substances radio-active. Those substances were said to have induced radio-activity. To quote the Curies:

"We found that any substance placed in the neighborhood of radium acquires a radio-activity which persists for many hours, and even days, after the removal of the radium. This induced radio-activity increases with the time during which it is exposed to the action of the radium up to a certain limit. After the radium is removed, it decreases rapidly, and tends to disappear. The kind of substance exposed to the radium is almost a matter of indifference. They all acquire a radio-activity of their own."

The ability to affect the electroscope was not the only peculiarity of substances which had been close to a bit of radium. They had also the ability to affect a photographic plate and in other respects proved to be truly radio-active. On some materials the induced radio-activity was several times as strong as that of uranium. At first it was the general opinion among

scientists that this induced radio-activity was something similar to what happens when a piece of iron lies near a strong magnet and becomes, in consequence, a magnet itself. However, this idea did not live long, for other experiments showed that something entirely different was the case. In these experiments, the Curies made use of the fact that certain materials become phosphorescent in the proximity of radio-active substances. Zinc sulphide shows this phenomenon to a marked degree. They placed a small quantity of radium in a small glass bulb and some zinc sulphide in another bulb. These bulbs were connected by a bent tube, provided with a stop cock. So long as this stop cock was kept closed, nothing happened; but as soon as it was opened, the zinc sulphide showed brilliant phosphorescence. This showed conclusively that some substance had been given off by the radium and that it had found its way through the bent tube. Something, acting like a gas, had come out of the radium. This substance was called radium emanation.

A great many experiments were made with this emanation—too many to mention them all here. However, some of them are of such importance and opened up such new vistas of the field of knowledge that they cannot be passed by. If some radium was heated, a much larger amount of the emanation was produced, but immediately after this, the radium itself showed a distinctly reduced radio-activity. It looked as if the emanation was a gas, occluded in the radium. The emanation would lose its power quite rapidly—that is, in a few days; and as its power became less, that of the radium grew in the same proportion. There is nothing strange in the fact that some gas was held captive in the radium. Such things are of common occurrence. Neither was it

strange that the gas was driven out by heat or that it could be collected by dissolving the radium compound in water and bubbling air through it. But what was remarkable was that after a while a new quantity of the gas could be obtained from the same amount of radium. It was plain that the gas was made in the radium. Radium has the power to change part of itself into something else. Here was something the alchemists had sought: the change of one material into another. And what was more, it did not need crucibles or other paraphernalia to accomplish this feat; it was entirely automatic, and inherent in the stuff itself. The rate at which this emanation is created in the radium is such that there is an equilibrium between that rate and the rate at which the emanation is dissipated.

Careful investigation of the emanation disclosed the fact that it, too, emitted positively charged particles, and later experiments proved that, in so doing, it changed into still another material. This again changed into something else, and even then the end of the process was not reached. Beginning with radium, there is a train of products, one after another, and at the end of the series we find, not gold, as the alchemist would have wished, but the base metal lead.

This is the series of substances into which radium changes itself:

Radium
Radium emanation
Radium A
Radium B
Radium C
Radium C_2
Radium D
Radium E
Radium F
Lead

The *end product*, lead, is of a slightly different nature, however, from the lead of industry.

A natural question comes now to our minds: Is radium really at the head of the entire series, is it the starting point, or is it, too, the result of such changes, and is it perhaps the product of another series of similar conversions? It was not long before this question was answered, and it was found that radium is the sixth term of such a series, and that uranium is at the head of it.

Uranium
Uranium X_1
Uranium X_2
Uranium II
Ionium
Radium.

A common property of all these materials is that they disintegrate spontaneously, and unceasingly.

CHAPTER XIII

Mostly Numbers

I MENTIONED atomic weights some time ago. There is much to be said about them. Scientists have been puzzling for years about them. The trouble with atomic weights was that they were so regular and yet not entirely so. If they had been entirely irregular, nobody would have given them a thought, and if they had been entirely regular, the very regularity would have led to some easy conclusion. But atomic weights were neither the one nor the other, though regularity prevailed.

There are at the present about ninety elements known to science—the lightest one, hydrogen, with an atomic weight of about one, the heaviest, uranium, with an atomic weight of 238. I used the word *about* when speaking of the atomic weight of hydrogen, and hereby hangs a tale, a very important one. Scientists are in the habit of looking for order and regularity in nature; and when they do not find it, they are apt to think that something was overlooked, or that some error has been made in their experiments or calculations. They are not easily inclined to blame nature.

When chemists began to determine the atomic weights of the elements that were then known, they naturally took as a unit the lightest material, hydrogen; and so they started with the atomic weight of hydrogen as 1. They found that many of the other elements had atomic weights which were very close to integer numbers. For instance, the atomic weight

of oxygen was very close to 16, that of carbon close to 12, etc. That they were not exactly whole numbers was easily explained by the assumption that the material was not entirely pure or that the experimenter had made some small error, so that it was highly probable that integer numbers would have been obtained if only these little errors could have been avoided. As the art of experimenting progressed, and more and more delicate methods and instruments were invented, it became evident that it was not possible to explain the discrepancies in that way. In many cases the variations from the whole numbers were several times as great as the probable errors of observation. At the same time it was noticed that if one would take the atomic weight of oxygen as the starting point—that is, if one would say that its atomic weight is *exactly* 16, and not *about* 16—many of the puzzling discrepancies disappeared, and a large number of the atomic weights became integers. However, even then, there remained quite a number of elements whose atomic weights could not be expressed by whole numbers. Giving oxygen the atomic weight of 16, hydrogen had no longer the atomic weight 1 but 1.0078. And this is the reason why I used the word *about.*

In the early days, when many chemists believed that the deviation from integer numbers was due to lack of refinement of methods, Prout suggested that the various elements might be compounds of the atoms of hydrogen. So, for instance, carbon would be simply a compound of twelve atoms of hydrogen, oxygen one of sixteen, mercury one of two hundred, and so forth. This idea was never accepted, but it had the merit that it set others thinking along the same lines, and when many people begin to think about the same subject, something is bound to be born,

be it good or bad. Mendeleef struck an idea which is now considered as hitting the truth and which has been extremely fruitful. You remember my saying that a theory, in order to be accepted, must explain the known facts, and must also be able to foresee some things which until then had not been observed. Mendeleef's theory did all this. It is now known as the *periodic table.*

In the periodic table the elements are arranged according to rising atomic weights, but they are not placed in a line. When we begin grouping them that way, we notice that the chemical properties of the first eight elements are widely different, but that number nine presents a decided family resemblance to number one; number ten corresponds similarly to number two; and so on until number seventeen is reached, when again there is the family resemblance to number one. To arrange the periodic table, we place the first eight in the order of their atomic weights in a horizontal row. We then place the next eight under the first one. However, we drop the idea of ascending atomic weights. Instead, we consider their family resemblances. For instance, number one in the first horizontal row is lithium, number two is beryllium, number three boron, number four carbon, number five nitrogen, number six oxygen, number seven fluorine. If we were controlled by the increasing weights we would have to place sodium in the eighth place, but this metal shows a strong resemblance to lithium, and so we place it under this element and not next to fluorine. Figure 12 shows the periodic table as far as it has been completed up to the present day. You will notice that there are a few gaps left. However, there were many more gaps when this table was first suggested by Mendeleef, and this table has proved to be a real theory and not merely a clever

guess, because Mendeleef was able to predict what properties the elements would have which would fill in the gaps left when he constructed the table. Subsequently several of these missing elements were discovered, and their properties were exactly as Mendeleef had predicted. There are still a few missing, but I would not be surprised if they, too, should be discovered between the first and the last chapter of this book.*

There are altogether ninety-two places in the table, and the various elements are known by their number in the table. So, for instance, uranium has number ninety-two, iron number twenty-six, nitrogen number seven, etc.

When I said that lithium is in the first row, I really meant to say that it was in the first more or less complete row, for there is only one element in the first, namely hydrogen. The columns, the vertical rows, are the ones which show the family traits. There is, for instance, the column of which helium is the first member. The various elements in this column show perfect resemblances, for they are all inert gases, gases which will not combine with any other element. This is the main reason why it took such a long time before any of them were discovered. However, after the periodic table had been accepted as part of the constitution and by-laws of nature, it became easier to find those which had not yet been found, for then we knew what to look for.

Prout's idea that all the various elements were built up from hydrogen atoms did not live very long. It was not a good theory, for it did not explain many of the facts known at that time (1813) and it did not predict new phenomena. Nevertheless, it was not so far from

*The few remaining empty spaces in the table were filled while this book was being prepared.

the truth as was thought at that time and many years after. Though, at the present, we no longer believe that hydrogen is the only building stone out of which all the various atoms are made, we do believe that atoms are built up, and only two elements have been suggested as being the prime materials of which atoms are made. They are hydrogen and helium. And it is believed by many that helium itself is made up of four atoms of hydrogen closely packed together.

The search for some uniformity, some regularity, in the system of atoms has been going on for many years, but for a long time no satisfactory explanation could be given for the fact that there were so many atoms of which the weight was fractional. The idea that this was the result of inaccurate measurements had to be given up when methods and instruments were capable of determining atomic weights within a very small fraction of the supposed error. The only suggestion which seemed to have some merit was that, possibly, some of the so-called elements were not elements at all, but were compounds of some of the other elements, or, perhaps, of some elements which had not yet been isolated. This was a mere suggestion and could not be proven at the time it was made or for many years afterward.

It is only in the last few years that conclusive experimental proof has been obtained that many elements are not elements at all, but a mixture of elements. As an example, take chlorine, which has an atomic weight of 35.46. This element is really a mixture of two other elements, with atomic weights of 35 and 37 respectively. The reason why it was not discovered sooner that chlorine is not an element in the commonly understood sense of the word is that the two constituents are chemically alike, so that there

is no possibility of separating them by chemical means. Each of the two is chlorine, so far as all of their actions are concerned. They differ only in weight, and it was only after other than chemical means were employed to separate the one from the other that success was obtained.

Such components of a chemical element are called *isotopes*. It is highly probable that all the elements which have fractional atomic weights are mixtures of isotopes. Quite a number of elements have been definitely analyzed. Here are some samples:

> Neon (an inert gas, found in the atmosphere) has two isotopes.
> Silicon has two or three.
> Argon, another inert gas of the atmosphere, has two.
> Chlorine has two.
> Bromine has two.
> Krypton, still another inert gas of the atmosphere, has five or six.
> Mercury has five or more.

You see that the art of separating elements into their isotopes is still in its infancy for in many cases there is even yet some uncertainty as to the number, but not as to the existence, of the isotopes. With others, such, for instance, as chlorine, there is no doubt whatever. There is a question which may have come to your mind, and which has come to the minds of many scientists, which deserves an answer even if you do not ask it. Chlorine, it was said, is made up out of two isotopes, one with an atomic weight of 35 and the other of 37. A very simple equation would show that, if this is so, then there must be 77 atoms of the first kind and 23 of the second kind in every 100 atoms of the mixture. I can hear somebody say: "That may be the case with the sample of chlorine which *you* had, but how about some other samples? How about chlorine in general?"

The answer is that the atomic weight of chlorine, wherever and whenever tested, has always been the same, and, therefore, the proportion of its isotopes is always the same. The possible error in the atomic weight of chlorine is so small as to be negligible, for this weight has been determined by many different experimenters and by many different methods, and all agree on the figure given. At first sight it seems to be a practical impossibility that two substances should be mixed in different parts of the world and under different conditions and without any formula or program and that all the mixtures should have the same proportion of ingredients. On second thought, however, this regularity does not seem strange at all.

Suppose you had two large heaps of materials, say sugar and flour. The ratio of their weights is as 23 to 77. You mix a little of the one with some of the other in a perfectly haphazard way and lay that mixture down somewhere. You do this over and over again and always without any care as to the proportion of the two materials. You keep this up until all the material is mixed and is now lying in little heaps in various places. Now you take some of one heap and mix it with some of another, and you keep up this performance millions and millions of times, just as nature has done for millions and millions of years. Don't you think that finally there must be a most perfect uniformity in the mixtures of all the little heaps you made? Of course, if somebody had taken some of your heaps of material long before you were through with your performance and carried them away to some other room where he did the further mixing, conditions would have been different at the end. You would then find that all your little heaps have the same consistency, and so would his, but his mixture would not be the same as yours and neither of the two would have the same propor-

tion of ingredients as you had at the start, namely 23 to 77.

Nature has been mixing the chlorine constituents for untold ages, and now chlorine is the same thing wherever we get it. But nature has not done so with all elements which have isotopes, and with such elements we may find some difference in the proportion of the constituent parts. One of these elements is lead. When radium disintegrates, the final product of this disintegration is lead. Lead is also the end product of the disintegration of another radio-active element, thorium. Not only that, but either radium or thorium may arrive at its end station along different routes, radium along two different routes, thorium also along two routes. And then there is still another radio-active element, actinium, which is, like radium, a descendant of uranium, and which, in its turn, gives lead as the end product along two different ways. There are then six different ways in which lead may be created by radio-active substances. One way of producing the lead may have been followed here, and another way there; and the end products, the different pieces of lead, may be mixtures of their isotopes in different proportions. These pieces of lead in different localities do not get intermixed as were the little heaps of flour and sugar, so that we may expect to find different proportions in different localities. This is exactly what has been found to be the case. The atomic weight of ordinary lead, as we know it, is 207.2 but some lead was obtained from thorite, found in Ceylon, which had an atomic weight of 207.69. This lead was obviously the end product of disintegration of thorium. Other samples were found in other places which had atomic weights ranging from 206.8 to 207.7. This shows that the consistency of the proportions of the various isotopes of chlorine and other metals is due to the fact

Periodic Table

					1 H					
2 He	3 Li	4 Be	5 B	6 C	7 N	8 O	9 F			
10 Ne	11 Na	12 Mg	13 Al	14 Si	15 P	16 S	17 Cl			
18 A	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni
	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br			
36 Kr	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 ?	44 Ru	45 Rh	46 Pd
	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I			
54 X	55 Cs	56 Ba	57 La	58 Ce	59 Pr	60 Nd	61 ?	62 Sa	63 Eu	64 Gd
					73 Ta	74 W	75 ?	76 Os	77 Ir	78 Pt
	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 ?			
86 Nt	87 ?	88 Ra	89 Ac	90 Th	91 Ur X_{11}	92 Ur				

FIG. 12.

that nature had a hand in the mixing for so long a time that further mixing can no longer change the proportion of the ingredients.

There are a few other things about the periodic table which do not seem clear at a first glance, but which, after all, have been satisfactorily explained. We shall probably run up against these things on some of our wanderings.

CHAPTER XIV

The "Widow's Cruse" Again

THE total amount of radium available for scientific research was extremely small during the first few years after its discovery, and even now there is so little of the precious material that it is not possible to satisfy the demands of the medical profession, which needs it for its practice and those of the scientific world which must have it for the checking up of data, so far obtained, and for new discoveries, which may be the result of more extended tests and experiments. However, science is now in a better condition to be sure of the results of experiments than it was the first few years after the metal was discovered.

For instance, the amount of emanation which could be drawn off from an extremely small piece of radium bromide was so small that it could not be ascertained with any degree of certainty whether it was a gas or not. Now, however, this matter is fairly well settled, and it is taken for granted that the emanation is a gas. It is called Niton. You will find it in the periodic table under this name. It is in the column of inert gases. In order to find if this gas had any chemical affinities, it was drawn over various substances which were red hot, so as to make it easier for the emanation to combine if there was any possibility of such combination at all. It did not respond to this treatment. Furthermore, other facts, which were brought out later, showed that it must have the atomic number 86, which would automatically place it in the column of inert gases.

The fact that radium is found in uranium ore led to the suspicion that it might be a product of the disintegration of uranium, and there is now so much evidence that this is actually the case that it is generally accepted as the truth. However, it is not thought that all of the uranium ultimately changes over into radium. Some of it becomes radium in its downward career and some becomes actinium; but after all, this is merely a way of saying that both radium and actinium are half-way stations on the road between uranium and lead. Maybe uranium is not the first in the progression, maybe lead is not the last, but so far as we have been able to find up to the present day, uranium and lead are the beginning and the end of the series.

Figure 13 shows how this downward movement progresses. When I say downward, I refer to the diminishing atomic numbers and atomic weights. You will notice that most of the names given to these various substances are old names with some symbol added to them. For instance, you find radium A and uranium II, etc. However, here and there, an entirely new name appears. There is, for instance, ionium or polonium or actinium. The reason why these substances were so favored was that it was not at once recognized that these elements, too, were disintegration products of the same element. It was thought at first that an entirely new radio-active material had been discovered, and only later was it found that the same element, uranium, was the father of them all.

If you take a mass of uranium ore at random, you will find some of its disintegration products mixed with the uranium. Probably all of the terms of the series may be found in the ore, but some of them would be present in such infinitesimal quantities that they

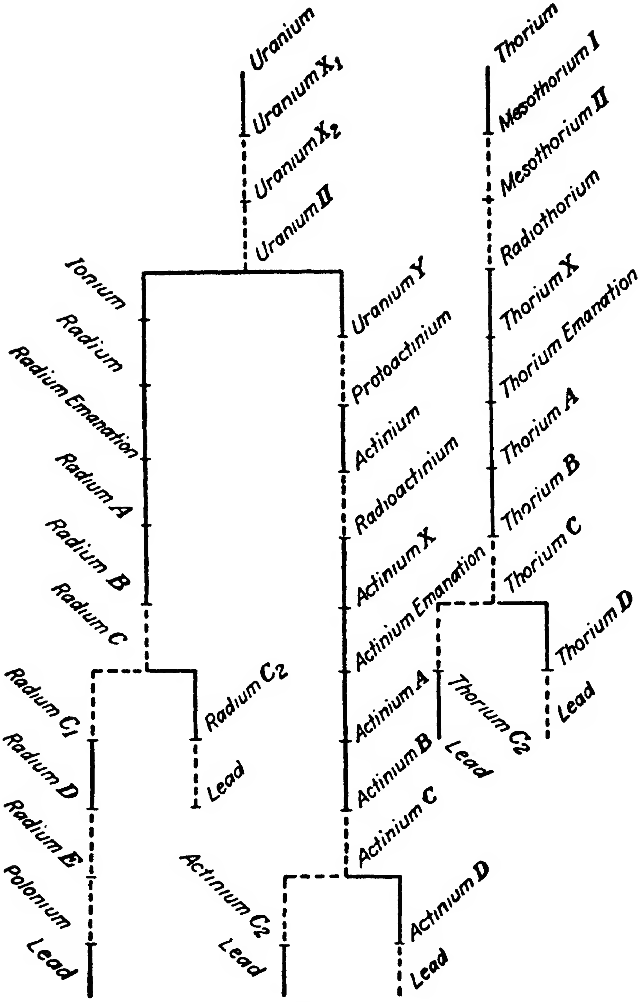

Uranium
Uranium X1
Uranium X2
Uranium II
Ionium
Radium
Radium Emanation
Radium A
Radium B
Radium C
Radium C1
Radium D
Radium E
Polonium
Lead
Radium C2
Lead
Uranium Y
Protoactinium
Actinium
Radioactinium
Actinium X
Actinium Emanation
Actinium A
Actinium B
Actinium C
Actinium C2
Lead
Actinium D
Lead
Thorium
Mesothorium I
Mesothorium II
Radiothorium
Thorium X
Thorium Emanation
Thorium A
Thorium B
Thorium C
Thorium C2
Lead
Thorium D
Lead

FIG. 13.

would not be discoverable. The reason for this is that some terms of the series disintegrate in such a very short time that it is extremely difficult to find them at all, even if they are not mixed with anything else. Other terms have a long enough life to stay with the uranium. There is, for instance, radium which has an average life of eighteen hundred years. This term "average life" is commonly used to indicate that in that length of time the amount has diminished to one-half of the original. Such a name or conception was needed because the rate at which any one of the radio-active materials disintegrates is not a constant *amount* but a constant *percentage*. For instance, if radium loses one-half of its mass in the first eighteen hundred years, it loses one-half of the remainder in the next eighteen hundred years, and this is true of all the radio-active materials known, except, of course, that the rate is not the same for all of them. Those which have a slow rate may be found with the mother ore, while those which have a very rapid rate have escaped or are escaping while the search is on. When I say that half the amount of radium has disappeared after eighteen hundred years, I do not mean that a piece of material weighing one pound is reduced to half a pound at the end of that period. You will find that the piece still weighs close to a full pound, but there is only half a pound of real radium. The rest consists of some of the disintegration products, such as lead.

As a consequence of all this the Curies found other substances in the uranium ore besides the radium, and they did not at first realize that these, too, were disintegration products of the uranium. In a way it may be said even now that actinium belongs to a separate series, for, though it descends from the common ancestor uranium, yet it, in its turn, is the main

stem of another family tree. However, this cannot be said of ionium or polonium. By the way, this name polonium was given to what Madame Curie thought to be a new radio-active material, in honor of the land of her birth, Poland.

Altogether, there are at the present two series of radio-active materials known: the one beginning with uranium and the other with thorium. Thorium is the material of which the salts are used to impregnate the Welsbach gas mantles. Both series lead ultimately to lead. It was thought at first that this lead was not the lead we know, but really some different substance which merely resembled lead. Later it was found that the differences between the lead of disintegration and that of industry was merely a difference of atomic weight and this was easily explained when it was found that lead, like so many other substances, was not a single element but a mixture of isotopes.

Somewhere else I mentioned that it is comparatively easy to find the ratio between the mass of an electron and the electric charge it carries, and somewhere else again, that beta rays are the same as electrons. It was equally easy to ascertain the ratio of the mass and the charge of an ion of hydrogen, which is what is left of such an atom when one electron has been removed. This ratio was found to be 1845 times smaller. In both cases the electrical charge is the same as to amount, the only difference being that, whereas the charge on the electron is negative, that on the ion is positive. We come, therefore, to the conclusion that an ion of hydrogen weighs 1845 times as much as an electron. We also found that the alpha and beta rays are the same as the rays we found in the Crookes tube, though they move with a greater speed. The beta rays, then, are electrons, and the alpha rays are ions.

However, it was found that the alpha rays coming from radium, or from any other radio-active material for that matter, were much heavier than the ions of hydrogen. They were, in fact, four times as heavy; in other words, they had the same weight as the ions of helium. The natural question now was: "Is it helium or is it perhaps something else with the same weight as helium?" Unfortunately, at the time that this question first presented itself, the amount of radium in the world was so small that not enough of the rays could be collected to apply chemical tests; but fortunately, on the other hand, there is a method of chemical analysis which does not require large quantities of material to show with absolute certainty what material it is. This method is by means of the spectroscope, of which mention was made before.

Careful collection of what little of the alpha rays was available, and a refined application of the spectroscopic method, showed conclusively that the alpha rays were really helium, or rather, helium ions. Due to the extremely small quantity with which the experiment was conducted, there was a great deal of doubt among scientists as to whether this helium was generated by the radium. It was thought that perhaps a small amount of the gas had come into the instrument in some other way. It was even suggested that it might have been occluded in the glass of the instrument and that it had been released by the radium or its emanation, and some even doubted if there was any helium at all. However, later experiments with larger amounts of radium established beyond cavil that helium was created by some radio-active materials (radium among them) during the process of disintegration.

Gradually we have come to the generally accepted conclusion that all radio-active materials are subject

to a spontaneous process of disintegration; that this process consists in the breaking up of some of their atoms; that sometimes electrons (beta rays) alone are shot off, sometimes helium atoms (alpha rays) alone, sometimes both, and also often X-rays (gamma rays). Further, that whatever rays are discharged, a new element is the result, and that the end of the series of changes is always lead.

It is also clear now that this disintegration takes place at the rate of a fixed percentage of the total amount of the radio-active material. This percentage may be high or low, but it is always the same for the same material. All of the remnants, if I may call them so, may be present in one piece of the original material, and their quantities depend on their rates of disintegration. In other words, these various rates establish a natural state of equilibrium.

At a first glance it seems surpassing strange that there should be such a fixed rate, but the strangeness disappears when we consider this act of disintegration more closely. Our old friend the statistical average explains it all very neatly. All we have to keep in mind is that even the smallest piece imaginable contains enormous quantities of atoms. Just imagine a little cube of radium one-thousandth of an inch in length and remember that this dimension is half as much as the diameter of a human hair. In such a length we can lay side by side about 250,000 atoms of hydrogen; and, as an atom of uranium or radium is only about two and a half times as large in diameter as an atom of hydrogen, there can be 100,000 of these atoms on the side of our little cube. This means that in such a little cube there may be a thousand million million atoms. With this large number anything *will* happen that *can* happen at any given moment. There may be only a few atoms exploding at one place in the cube,

a great many in another place, and possibly none at all in still another. The average, however, will be the same for any cube of that size. When finally the piece has been reduced to so small a volume that only a few, say ten million or so, atoms are left, this statistical average may no longer be trustworthy; but in that case the amount of material is entirely too small for us to work with or even to observe. When, finally, a single atom is left, it may happen that it explodes at once or it may live a million years.

When this transformation of metals was first observed, it excited the imagination of the less scientifically trained minds. Visions were seen of the general transmutation of metals. Gold was to be made by the carload and some people looked forward with some anxiety to the day when the entire economical structure of the world would tumble into a heap; for what would happen if anybody could make himself as much gold or platinum as he might want? After all, they said, these old alchemists were not such fools as we used to think.

Unfortunately for those much in need of some gold, this thing does not work out that way at all. Radio-active materials change into other materials along a program of their own. Nothing we can do can alter the process. We can neither accelerate nor retard it. No heat or pressure, no chemical reagent has the slightest effect on it. And the worst of all is that, instead of producing the desired precious metal, it changes the very precious metal into the lowly lead.

To do justice to everyone, I must say that gold has actually been produced, though not from radium. At least, reports say that it has been done, though there is more than a mere shadow of doubt over it. It has been claimed that gold in minute quantities has been

made from mercury. However, the quantity was so small that there was some difference of opinion as to whether there was any at all. For this reason, and because what was produced cost a small fortune, I would not advise anybody to try to become wealthy along these lines. Almost any kind of work pays better.

CHAPTER XV

A Colorful Chapter

PRACTICALLY everybody knows about what Newton did with a glass prism. I sometimes wonder if this great savant had any inkling of what his discovery would lead to. Newton decomposed the ordinary sunlight into its seven components. At least he said there were seven, although later on people in general and artists in particular, said that there were only six. Newton said that light, the white light, was composed of red, orange, yellow, green, blue, indigo, and violet. The artist says that indigo is no separate color, and then comes the scientist who says that there are a few thousand colors, to which he gives no names at all.

Did Newton dream that his spectrum would allow us to find the minutest amounts of material; that it would let us discover new elements, the existence of which we had not even suspected; that it would tell us of what material the farthest stars are made; that it would disclose to us the structure of the atoms, and that it would enable us to calculate the orbits of the stars? He probably did not, though little do we realize how near the scientist and the dreamer are akin at times.

White light, the light of the sun, consists of a mixture of different kinds of light waves; not six or seven, but a great many. All of them travel with the same speed, but are of different lengths. We may therefore expect that they will part company as soon as there is some condition which is not equally suitable for all of them. Such a condition prevails when

the light passes from one medium, say air, into another, say water. The reason is that the speed of light is not the same in all materials; it is slower in a denser than in a less dense material. Even passing from the empty space surrounding our earth into its atmosphere changes the speed of light, but the change of velocity is so small in this case that the effects are not noticeable. The reason why they part is that when a ray of light strikes the surface of another medium at any angle except a right angle there will be a bending of the ray. In the new medium it makes an angle with the vertical which is different from the corresponding angle in the old one. In Fig. 14 a ray of light *AO* is supposed to make an angle with the surface which divides the two mediums. It has come through air and it enters water. The direction at which it will now go through the water is indicated by the line *OC*. Both lines *OA* and *OC* make an angle with the line which runs vertically to the dividing surface. The distances *OA* and *OC* are equal, so that the lines *AB* and *CD* are measures of the two angles with the vertical. If the two lines *OA* and *OC* are of unit length, then the lines *AB* and *CD* are called the sines of the two angles. Now, at whatever angle the ray of light may strike the dividing surface, the ratio between these two sines is always the same for the same two materials: in this case air and water, provided that we are dealing with the same kind of light. This ratio is called the *index of refraction*. This index may have widely different values. It depends on the kind of light which is refracted and also on the nature of the two mediums.

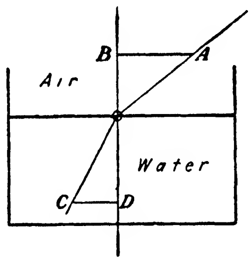


FIG. 14.

If we should use a beam of monochromatic light we would find that the index of refraction is rather small if we let the light pass from air to water; that it is much more when we let it pass from air to ordinary crown glass, and still much more if the second medium is extra heavy flint glass. A material which would give us a very large index of refraction is diamond.

It makes a difference, too, whether the light which is being refracted is red, green, or violet. The shorter the wave length, the greater the index of refraction. If a beam composed of two different colors of light should strike the surface of a new medium at an angle, both colors would be refracted, but not to the same extent. The one of smaller wave length would be refracted more than the other. Our daylight is made up of different kinds of light, and, as a consequence, it appears after refraction as a band of different colors: the well-known spectrum. To all appearances it is a continuous band. At one end we find red, at the other violet, and there is a gradual blending from one color to the other. It is not possible to say where red ends and orange begins.

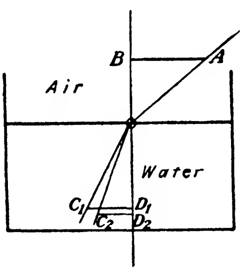


Fig. 15.

In Fig. 15 a beam of multicolored light strikes a mass of water at an angle. To avoid complications, the beam is supposed to consist of two kinds of light only. You see that the beam is split in two.

In Fig. 15*A* a beam of light is split up in a similar manner. This time it has come through air and enters glass. When the two beams come out again they are deflected once more and brought back to the original direction. However, though the direction has been

restored they are still apart and appear as two parallell beams.

The final result is that the light rays have been moved sideways and that the two colors are no longer in one bundle. They have been separated and are some distance apart. However, this distance is not great enough for finer observations. The problem is to increase this dispersion. Of course, the obvious thing to do is to

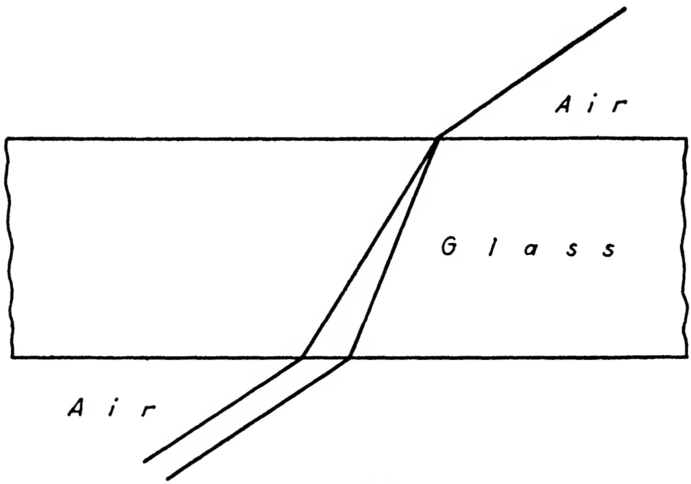


FIG. 15*A*.

let the split beam, as it comes out of the glass, enter another plate, and do this as often as may be necessary to spread the two colors the desired distance apart. A better way is to do what Newton did, that is, let the light go through a prism. Figure 16 shows how the two colors would be spread if such a prism were used.

When the beam enters the prism it is split in exactly the same way as when it entered the thick plate of glass, and the dispersion is no greater. When it leaves the prism the angle between the two beams is some-

what increased because they do not strike the second side of the prism at the same angle. However, this is not all. The main thing is that these two beams are not parallel. If we should intercept the light coming from the prism on a screen, and hold the screen close to the prism, the two beams would again be close together and fine observations would not be possible. However the two beams diverge, and so we can get any desired distance between them by holding the intercepting screen far enough away. When we used the single plate of glass, the beams were spread apart when they entered the glass, but were once more made parallel when they left, so that additional distance of the screen would not help.

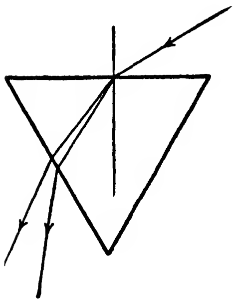


Fig. 16.

There is some objection to placing the screen far away from the prism. Unless the source of light is of great intensity, the image on the screen is apt to be very faint. On the other hand, unless we do keep a considerable distance between screen and prism, the various colors overlap. This difficulty may be overcome by letting the light pass through a second prism.

About a century and a half elapsed before the spectrum became something more than a plaything. Its real usefulness began with the discovery that various light-giving substances would give various spectra. The same substance would always give the same spectrum. I am making this statement here because that is what seemed to be the entire truth when first this remarkable property of the elements was discovered. Later it was found that the statement, as expressed here, is too broad, though it is sufficiently correct for our first look at what it means.

It means that we can discover what elements there are in a compound. It means that we do not need to have a material in our hands or near us to analyze it. It means that it is equally possible to analyze the materials which are found in a far away star as in a piece we have in the room. However, a further study of the spectrum showed that many things had to be considered and many new methods had to be developed before one could be absolutely sure of results. On the other hand, this further study brought new features of the spectrum in view, which made it useful to other branches of research.

To say it in a few words, the spectrum given by an element depends in the first place on the nature of the element itself, but further on its condition, whether it is hot or hotter; whether it is a solid or a gas; on the source of its temperature and, often, on the material between it and the instrument with which its spectrum is observed.

This instrument is the spectroscope. Reduced to its simplest elements the spectroscope consists of a prism to give the necessary dispersion, a set of lenses to observe the spectrum, and a fine slot through which the light to be analyzed can enter the instrument. As a rule the width of the slot is made adjustable. Further, there is a very small and very accurate scale in the instrument, an image of which, much enlarged, is focused in such a way that the observer sees the spectrum and the image of the scale in the same place.

If we wish to observe the spectrum of some element, the first thing to do is to make it luminous. This may be done in different ways, and we will get different spectra according to the method we use. If we bring a solid body to incandescence, we will get a continuous spectrum, that is, we will see all the colors

of the rainbow, one blending into the other. Such a spectrum would not tell us anything about the nature of the material. On the other hand, if we heat a gas to the point of luminosity, we will see a number of narrow bands placed in some definite way on the scale of the instrument. We will always get the same bands, and always in the same order, and no other element will give us exactly the same color of bands or the same placing on the scale. A good way to obtain the spectrum of gases is to have some of the diluted gas in a tube into the ends of which electrodes have been fused, and have an electric current go through the gas. The gas should be attenuated to about one-thousandth of atmospheric pressure. The beauty of this method is that the very smallest amount of gas shows its spectrum and can be identified. This is the way helium was identified as a product of the disintegration of radium. Quantities much smaller than would be needed for chemical analysis show up perfectly plainly.

In order to analyze solid substances it is necessary to vaporize them. This may be done in different ways. One way is to use an arc lamp, the electrodes of which are made of the material to be investigated. Of course, this requires a considerable quantity of the material. If but little is available, it may be placed in the arc made by different electrodes. We will then see the spectrum of the electrodes and also that of the material under investigation; and, as the spectrum of the material of the electrodes is known, that of the other material can be examined as if there were nothing else.

Still another way is to use the electric spark, such as is used—or rather, such as *was* used—in wireless telegraphy. A battery and induction coil furnish a small amount of current, but of high voltage. Sometimes a condenser is placed in the circuit to make the

spark stronger. The electrodes, or, as they should be called here, the terminals of the spark gap, may be made of the material to be investigated or some of this material may be placed between the terminals. In this manner we vaporize a small amount of the material. The method of the arc or the spark is especially useful when the material vaporizes at a very high temperature. When such high temperatures are not required, the material may be held in the flame of a Bunsen burner.

Though the arc and the spark can both be used, they do not give the same spectrum. The reason is that the first is obtained with low voltage and a large amount of current, while the second uses high voltage and a small amount of current. However, neither of the spectra is the same as that of any other kind of material.

The spectrum of the sun as seen through an ordinary prism is continuous; in other words, it does not show any specific lines which would tell us what elements may be found there. However, if we disperse the spectrum sufficiently, it ceases to be perfectly continuous. Dark lines appear, separating the colored portions from each other. These lines are called the Fraunhofer lines. There are a great many of them and all have been carefully catalogued. They are of the greatest importance in spectral analysis, for they depend on the fact that the light emitted by a substance is absorbed by the vapor of the same material. The central portion of the sun throws out the various light waves, dependent on the various materials existing there; but this light must pass through the cooler gaseous envelope, and here some of these rays are absorbed. If we see a dark line at the place where we would normally find the line for iron, then we know that there must be iron in the sun. It was

in this manner that an element was found in the sun which was not known on our earth. This element was called helium. Twenty-five years passed before it was found to exist here as well as on the sun.

I said that the spectrum permits us to determine the course of the stars besides telling us of what they are made. I must refer you back to the locomotive whistle. We found that sound has a higher pitch when its source approaches us or when we approach it than it has when the movement is in the opposite direction. Exactly the same thing takes place with light. Here, too, we catch more light waves per second when we approach the source, and this means in this case that the color of the light is somewhat different from what it would be if we and the source of light were standing still. A beam of red light would be more nearly orange, one of green light would be more nearly blue. The amount of displacement would depend upon the speed of the light source or of ourselves. This effect, which was called Rijke's phenomenon in the case of sound, is called Doppler's effect in the case of light.

It was noticed that the light from some stars did not give the proper kind of spectrum. There would be lines and bands of this, that, and the other thing; but the lines were not where they should be. This statement may almost seem to be impertinent, for who are we that we should say what a star must do? However, we take for granted that nature is regular in her habits; that, if she makes a set of lines for sodium on this earth, she will make the same set for a star. She did this very thing but the lines were not in the proper place. Somebody might ask how anybody can say with certainty which is the right place. Two different spectroscopes might place the spectra in entirely different positions. The answer is this, that if we see

the spectrum of sodium in a certain place on the scale we must see it there every time, whether the sodium is here or on some star, provided that we use the same instrument and have not disturbed its adjustment in the meantime.

Instead of depending upon personal observation, science depends nowadays largely upon the photographic plate. The camera makes no mistakes such as a human being would make. It does not get tired, but can go on observing the same object for hours at a time; and, what is best of all, it makes a permanent record of what it has seen and tells the story the same way every time. If we arrange the sensitive plate in the proper fashion, we may make two photographs on one plate. We may first make a picture of the spectrum of hydrogen here on earth, and then make another one of the spectrum of some star on that same plate. We can arrange things so that the one is immediately above the other and so that we can compare them at our leisure, and even measure the details. We would see that, with some stars, the astral spectrum of the hydrogen is a little to the left, and with some others a little to the right, of the spectrum of hydrogen on the earth. It might be objected that, perhaps, the astral spectrum is not that of hydrogen at all, but that of some other element. Here is where we must depend upon the regularity of nature. The astral spectrum shows exactly the same arrangement of lines as that of the hydrogen. As no spectrum of any other element does this, we must conclude that there is merely a little displacement. We can measure this displacement and from it calculate the speed of the star in the direction in which its light came to us.

There are several ways in which the wave length of light can be determined. They all depend partly on

observation and partly on calculation. Michelson determined the wave length of the red light emitted by luminous cadmium with a maximum error of one in two million. The light of several other substances has also been measured so that it is possible to place the figures of their wave lengths opposite some of the lines of the spectrum. The trouble with these figures is that they have so many ciphers. All wave lengths are very small fractions of an inch, and as there are so many different wave lengths bunched close together, we would get a tabulation of which the members would all begin with a number of ciphers, then some figures, and the important defining one or two numerals—like the sting of the scorpion—at the end. Ångström, a Swedish scientist, suggested a system by which these fractions would be avoided. He took as unit the one-hundred-millionth part of a centimeter, the two-hundred-and-fifty-four-millionth part of an inch. This unit has been called the Ångström, and all wave lengths are expressed in this unit.

The range of the visible rays is from seven thousand to four thousand Ångströms, so that it is possible to locate a great many lines in that part of the spectrum without using more than one decimal. However, even the Ångström does not let us give the various other wave lengths without a few ciphers. X-rays go down to as low as one-tenth, gamma rays to one-hundredth, and cosmic rays to perhaps one-thousandth of an Ångström.

Having determined the wave lengths of a few elements, we can now interpolate between these values, and in this manner give figures to all the lines we observe in the various spectra. We can say that the spectrum for such-and-such an element consists of one line at so-and-so many Ångströms, another line at such-and-such, and so forth. This makes it possible

to convey the results of observations from one observer to another. Not only can we do this, but we can measure the number of inches on our photograph of the spectrum which corresponds with a difference of a thousand Ångströms, so that we can plot the various lines of the spectrum on any desirable scale.

If we find that the spectrum of a star brings a line, which properly belongs in the place where we would find five thousand Ångströms, to the position of five thousand and ten, then we know the speed of that star by some easy calculation. There are a great many so-called double stars, which are systems of two stars revolving around a common center, just as the earth and the moon do, except that in most cases the two members of the system are more nearly of the same size. Some of these systems revolve in a plane which causes one of the two stars to eclipse the other. When this is the case, there is a time when one of them goes directly away from us and another time when it comes directly toward us. If the spectrum of that star is observed at such moments, the Doppler effect will give us all the necessary data to calculate the speed of that star. Both observations are required; that is, we must get the Doppler effect when the star goes and when it comes. The going alone would tell us what speed the star has in relation to the earth, but we would not know whether this is due to the movement of the star, or of the earth, or perhaps partly of the one and partly of the other. When we have found the speed of the star around the common center and we have also noted the time of revolution, we can calculate the length of the orbit, and we can do all this by looking carefully at some colored lines which the light of that star makes in an instrument of our devising.

The sun, like the earth, rotates on its axis. When we focus the spectroscope on one edge of the solar disc we get a spectrograph which is displaced a little to the right, and when we focus the instrument on the other edge we find the spectrograph displaced toward the left. Careful measurements of these displacements, and a little calculation, show us the speed of a point of the solar disc. If we know the diameter of the sun, we have all the necessary data to compute its period of revolution. The problem remains how to find that diameter.

This is easy enough if only we know the distance from the earth to the sun, but, as some sceptics would say: "You can tell me what that distance is, but how are you going to prove it? You can't go there." This is very true, we cannot go there, but every day the surveyor measures distances to points he cannot reach. If he wishes to measure the distance to such a point, he begins by measuring what he calls a base line, that is, the distance between two points which he *can* reach. At one of these two points he directs the telescope of his instrument to the point which he desires to locate and also to the other end of the base line. He does the same thing at the other end of the base and so gets the necessary data to calculate the distance wanted. You see, the two points of his base line and the remote point, the distance to which he wants to measure, are the three corners of a triangle. Of this triangle he knows the base and the two angles which this base line makes with the two lines that run from the ends of the base line to the remote point. Whoever does not know how to calculate the desired distance, when he has these data, is referred to any text book on trigonometry.

It is in this manner that the distances to the sun and the moon and some of the planets are obtained.

If we want to get the distance from the earth to the moon, we select two points on the earth of which the distance is known. We direct our telescope from these two points to the same point of the moon, and, of course, do it at the same time. We have then exactly the same set of conditions which our surveyor had when he measured the distance to the point he could not reach. I have been a little free with the details, but the principles are not affected by the fact that an astronomer would do it a little differently. For instance, it would not be practical to try to have two observers at different places make an observation at exactly the same moment. After all, this is not necessary. The astronomers would wait until there is a sun eclipse and two or more of them would observe the precise moment when the edge of the shadow of the moon touches the sun. That time would be different for two observers, and this difference can be converted into angles which bring the problem to the condition in which we first imagined it to be. The distance to the moon is 238,857 miles, but if ever I refer to it again I'll call it 240,000 miles; it is so much easier to say.

In a similar way the distance between us and the sun might be found, but there are other and better and, certainly, more interesting ways. One of these methods may be described here, not alone for what it accomplishes, but also because it makes use of a phenomenon which proves beyond the possibility of doubt that the earth rotates around the sun, and not the sun around the earth. Moreover, it shows how the scientist makes use of seemingly unimportant and detached things to solve deep and dark mysteries.

Astronomers have always been interested in the distances between us and the various heavenly bodies. What seems to be the simplest way to find these

distances is by measuring the *parallax.* This is a forbidding word but a rather simple thing. Imagine that I want to find the distance between me and a certain tree which I cannot reach but which I can see. To do so, I take a telescope and direct it toward the tree. I then take a new position and do the same thing again. If now I know how far my second position is from the first, I have reduced my problem to a simple problem of trigonometry and any surveyor and many school children can solve it. The distance between us and the moon was found this way.

Applying this method to the problem of finding the distances of the stars, I take two looks at some star; one, when we are at some point of our travel around the sun, and another when we are at another point. Of course, the farther the two points are apart, the more accurate our result must be and so we make our observations half a year apart. Even then we find that there is but a very small difference in the directions of our telescope, so small in fact that only the very finest instruments show any difference at all, and then only for those stars which are relatively close to us. This is so because the distance between the two points from which we have made our observations are so close together, a mere seventeen light *minutes,* whereas the nearest star is four and a half light *years* away.

To the extent that we succeed with this method, we shall see that a star seems to describe a small circle, which is really saying that we had to turn our telescope through this circle during the year of our observation, and this was so because we had traveled through a circle during that time. Of course, the farther away the star, the smaller the circle.

Bradley tried to find the distances of various stars this way. In his time instruments did not have the

same degree of refinement which they have now, and he did not get very far in his measuring of the parallax. However, he saw something else, which was at first rather bewildering. He did see that many stars seemed to describe small circles, much larger, in fact, than he had reason to expect, and all of the same size. Of course, this could not be parallax, for stars at different distances from us must show circles of different sizes. It is generally when things go wrong with scientific experiments that something new is discovered. Some of us might have been inclined to throw our pencil down and swear, but not so Bradley. He pondered long and deeply and finally came to the conclusion that what he had seen was not due to parallax but to what is now known as the *aberration of light.*

Imagine that you are standing in the rain. There is no wind and the water is coming down vertically. You have a tube in your hand which you hold straight up and down. The walls of your tube remain dry, provided that you have made the upper opening a shade smaller than the size of the tube. You begin to walk, always holding the tube vertical, as before, and now you notice that the inside is becoming wet on one side. However, you can prevent this by holding the tube at a small angle with the vertical. You should adjust the angle so that a raindrop which enters the tube at the center of the top leaves it at the center of the bottom. How great that angle is depends on the speed with which you walk. If it takes the raindrop one second to travel the length of the tube, and you have walked one foot in that time, you must hold your tube so that the top is one foot further forward in the direction you are going than the bottom is. If you know the rate at which you are going and the angle at which you must hold the tube to keep the inside dry, you can compute the speed of the raindrop;

and if, on the other hand, you know the speed of the raindrop and the angle of the tube you can figure out how fast you are going.

Now, when we are looking at the stars, we are holding such a tube, the telescope, and we are moving along, traveling around the sun, but we have no raindrops. Instead, we have rays of light. Sometimes we move in one direction and then again in another, because we are moving all the time in a circle, or nearly so. If we want the ray of light coming from the star to get to our eye and not wet the inside of the telescope, we shall have to shift the direction of our instrument as we go along. If we know the angle of this shift, and the speed at which we go, we can compute the speed of the raindrops—I mean the light rays—and if we know the speed of light and the amount of shift of the telescope, we can figure out how fast we are going. As a matter of fact we do know the speed of light, and we can read off on a dial the amount we had to shift the telescope in order to keep the star in sight; and so we can calculate the speed with which we are traveling around the sun. If we find that this speed is so-and-so many miles a second, and we multiply this amount by the number of seconds in a year, we have then the total length of our orbit around the sun, and to find the diameter is a simple problem if we know the circumference. This distance is 92,870,000 miles and I'll take the liberty of calling it 93,000,000 miles. With the diameter of the orbit around the sun as a basis, we can now calculate the distance of the stars—at least of some of them, those that are closest to us.

The prism had been appreciated a long, long time. It lent splendor to palatial halls when it dangled from the chandelier. It gave the wonderful display of light and color to the diamond. And, by the way, the dia-

mond would not be such a coveted thing if it were not that its index of refraction is so great. It may truthfully be said that the most valuable attribute of the diamond is its index of refraction. Much as the prism was used and valued, it is only for a hundred years or less that it has been used as anything but a plaything. It is now one of the most important instruments used to penetrate the secrets of nature. Even those of the invisible atom had to yield to the penetrating eye of the prism. It is but natural that such a position of prominence cannot be occupied indefinitely without some competitor trying to oust the favorite and take its place. The prism still holds its place, but no longer alone. It has a rival.

CHAPTER XVI

Scratches

SOME things are accepted by us but with a little doubt left in the background; of some things we are fairly sure and of still others we are so certain that we do not even think about them. One of these latter things is the belief that light proceeds along a straight line. Light does not go around a corner as sound does.

It is always somewhat of a shock to us when someone comes and tells us that what we considered to be the incontrovertible truth is, after all, not so. When Einstein said that light was subject to gravitational pull and that therefore a beam of light would bend away from the straight line if it passed near enough to a body which could exert such a pull, we were all inclined to shake our heads and ask "What next?" When it was found that Einstein's prediction could be verified by experiment, we felt that another stone in the foundation of our beliefs had been pried away and we began to wonder when the entire structure would come tumbling about our heads.

Einstein predicted that a ray of light from a star would be deflected when it passed close to the sun. Ordinarily it is not possible to make any observations at all about a star when its light passes the sun. The sunlight drowns out the light of the star. But there is a time when the sun may be in the high heavens and when we can see the stars nevertheless. This happens when there is a total eclipse. The sun is there with all of its gravitational pull but its

light is dimmed. At such a time we can observe a star the light of which must pass close to the sun. How do we know whether its light is deflected or not? This is a simple matter. We know the relative positions of the stars from observations made at night. Photographs have been made of them. When we observe the stars during an eclipse we find that some of them are not in their proper places. If anyone doubts whether perhaps an error of observation was made, a look at the photographic plate will reassure him. He will see that a few stars are not in the same relative position to other stars as he will find them on other plates which were made at some other time at night. This fact that the sun would deflect a ray of light is considered one of the main proofs that Einstein's theory is a real theory, for it is able to predict the existence of phenomena heretofore unknown. As if this were not enough, the theory is also able to explain a mystery which had been unsolved until then.

The orbits of the planets are well known. We know that they travel in elliptical paths. We know the major and minor axes of these ellipses; we know the exact time of their cycles. All these data are computed on the basis of the Newtonian theory of gravitation. All calculations corresponded with the observed facts. All, that is, except one. The path of Mercury showed a slight variation from the calculated data. However, other calculations, as well as observations, came to our assistance and it was found that, still holding on to the Newtonian theory, the path of Mercury was not always in the same place. Suppose you draw an ellipse on paper, and then, using one of the foci of the first ellipse, you draw another with the same elements —such as the size of the two axes—but a little off to one side. This will give you an idea of what Mercury does year after year. It describes the same ellipse

but in a slightly different place, and always using the sun as one of its foci. All the necessary knowledge was at hand to calculate the amount of the annual displacement of the orbit. The calculations were made by the astronomers with the degree of accuracy and refinement we expect and receive from an astronomer; and then it was found that the facts, as observed, did not agree with the result of the calculations. The theory explained part of the displacement, but not all of it. Einstein's theory led to calculations which gave another amount of displacement than did the Newtonian theory, and the result of observations agreed with the calculated value to within a small part of what might have been considered as permissible error of observation. It now takes a bold man to say that the theory of relativity is not to be taken seriously.

We have gotten away from the direction of a beam of light. My story has been deflected, too. I was about to say that, after all, we should not have been so much disturbed by the fact that the attraction of the sun deflects a beam of light, but I wandered off into side paths. What we should really say about the direction of light is that it travels in a straight line if there is nothing to make it travel some other way. If it enters some other medium, its direction is changed, so that the total path of the light is then a broken line. If it passes over a heated desert, meeting constantly changing densities, it describes a curved line, and when it strikes a mirror, it is turned back upon itself. But this is not all. Physicists knew for the last hundred years or more that light will go around a corner, though not to the same extent as sound.

Place a source of light in a darkened room. An electric light bulb may be used. Cover this light but

let some of it escape through a pinhole. Place a disc of some thin material some distance away, so that it is illuminated by the light. See to it that the disc has sharp edges. Place a screen, preferably white, some distance further, so that the shadow of the disc will fall upon it. If you have made the disc eight inches in diameter, if it is one foot away from the pinhole, and if the screen is again a foot from the disc, you should get a sharp shadow sixteen inches in diameter, because the screen is twice as far from the source of light as the disc is. Measure the shadow and you will find that it is less than sixteen inches and that it is not sharp. The outside edge of the shadow is colored. It shows the colors of the rainbow. The light must have curved around the edge of the disc. There is no other way of explaining the fact that the shadow is smaller than it would be if light traveled always in a straight line.

This phenomenon—that light bends around a sharp edge—is called diffraction. If a monochromatic light is used in the experiment, there will be no colored fringe, but it will still be found that the diameter of the shadow is too small. It makes no difference what color is used. The shadow is always too small, but it does not always have the same diameter. This depends on the color of the light. This shows that, although all colors are subject to this bending, they do not bend the same amount, hence the rainbow fringe when white light is used.

Huygens' wave theory of light explains the phenomenon of diffraction completely, but it would lead us too far afield to go into it. It was observed in his time, but, like the prism, was left to rest for a long period. Now it has become the competitor of the prism in spectral analysis.

The analyzing element is what is called a diffraction grating. This is a flat piece of polished metal on which a large number of very fine lines have been engraved. It is difficult to form an idea of the care and skill required to make such a grating. It sounds like something any skilled mechanic should be able to do: just making a flat piece of metal and engraving some straight lines on it. As a matter of fact, engraving these lines is an exceedingly difficult operation. What is involved in making a really *flat* piece we have seen before now.

Many thousands of lines are engraved to the inch. This in itself is not so difficult, but the lines must be sharp and the distances between them must be equal. If we draw two lines on a piece of metal one inch apart and we wish to be sure that the error in their distance shall not be more than one per cent, we need to take care only that the actual distance does not fall short of one inch, or exceed it by more than one-hundredth of an inch, and this is not difficult to do. If we draw lines one twenty-thousandth of an inch apart and wish to keep our errors down to less than one per cent, we may not make an error exceeding one two-millionth of an inch, and this is almost impossible. Yet such gratings have been made.

There are two kinds of such gratings in use: the transmission and the reflection gratings. The one with the lines engraved on it is a reflection grating; the other kind has very narrow slots very close together. Reflection gratings, though difficult to make, are very common. Did you ever admire the beautiful irridescent coloring of some butterfly wing, or the shifting light and color of some gem? Well, you were then admiring the effect of the diffraction grating with which nature has provided the insect or the stone.

There are a great many experiments about diffraction which anyone, who has a mind to, can carry out at home. Figure 17 shows the arrangement for one of these experiments in diagram. *A* is the source of light. This light should be hidden in a box of which the front wall is represented by the heavy line *XY*. A slot is made in this wall as shown. Such a slot should be narrow and have sharp edges. Some distance in front of the box the screen *MN* is placed, and here we have another slot. Still some distance further there is another screen, preferably white. The slot

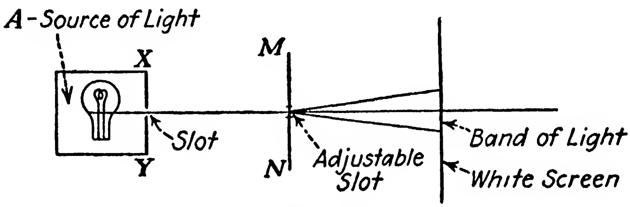


FIG. 17.

in the first screen should be adjustable as to width. An easy way to do this is to use two pieces of cardboard, each with a fairly wide slot in it. By moving one piece over the other the resulting slot in the screen may be made as narrow as desired. As soon as the slot is sufficiently narrow one will see a broad band of light on the second screen, and the narrower the slot the broader the band of light. This shows that the rays of light were bent. They must have spread out after they passed through the slot in the screen *MN*.

Another interesting experiment which anyone can carry out is the following. Again take a source of light, such as an electric light bulb, and enclose it, but this time make only a pinhole in the front wall. The screen *MN* is this time a thin circular piece of

metal. It should be truly circular to get the best effect, and it should be only about a fourth of an inch in diameter, though any other small dimension would do equally well. One would naturally expect to see a shadow of the circular piece on the screen, and this is actually the case except for the fringe mentioned before. However, if the circular piece is slowly and carefully moved toward or from the source of light, there will be one position in which the shadow shows some entirely unexpected peculiarities. At that point a bright point of light will be seen in the exact center of the shadow, and going from the center to the cir-

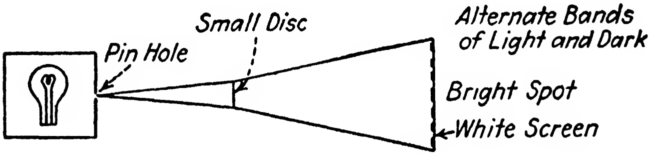


FIG. 18.

cumference one will see alternate circles of dark and light. The light bands lose in brilliancy as one goes further from the center, and even the lightest of these bands is not nearly so brilliant as the center itself. The arrangement is shown in Fig. 18.

The mathematics of the phenomenon of diffraction are quite involved and cannot be discussed here. Be it sufficient to say that the spreading of the light by this means also allows the separation of those sources of light which are close together, so that it is possible to examine in detail the colored bands and lines of the spectrum. More than that. As the spreading depends on the wave length, the amount of separation of the different lines furnishes us with a means to determine with a high degree of accuracy the wave length of each line in the spectrum.

It is a peculiar thing that a few scratches on a piece of metal should enable us to say with certainty of what material the stars are made and to measure things so small that their dimensions must be expressed in millionths of an inch. If this were all that the diffraction grating could do, we would certainly have to agree that it is enough. But these scratches do more. When in 1895 Roentgen discovered the X-rays no one was sure what they really were, and hence their name, the X was the unknown. There seemed to be no way of doing what the scientist wants to do first: measure them. There are other rays, too, which are not easy to measure. There are, for instance, the so called infra-red and the ultra-violet rays. These radiations are found at the ends of the spectrum. One might almost call them colors without color. We cannot see them. They are beyond the capacity of the eye. However, we can feel the infra-red rays because they give heat and there is no necessity to prove that there are ultra-violet rays. Everybody is familiar with them, or at least with their name. In the popular mind they are the health-giving rays. They can cure everything except broken bones. Hospitals are being provided with window panes which will let them through; and thousands of people spend their vacation money to let the ultra-violet rays give them a coat of tan.

As to these window panes: we are under the impression that glass is transparent, and so it is, if we specify. Glass is transparent to ordinary light, but not to infra-red or ultra-violet rays. As a result we can analyze ordinary light with the prism, but if we wish to know anything of the infra-red rays the prism fails us because glass will not let them through. However, a prism made of clear rocksalt is transparent to these rays and this gives us a chance to analyze

and measure the infra-red rays too. As to the ultra-violet rays, they require something else again. In their case we can use a prism of quartz, but even with the help of this material we have to confine ourselves to those ultra-violet rays of which the wave length is not very much shorter than that of the shortest visible rays. By the way, pure quartz, such as is sometimes found in nature, and as is nowadays manufactured as fused quartz, is much more transparent to

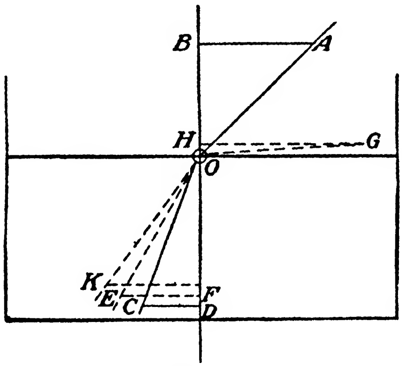


FIG. 19.

ordinary light than glass. Glass lets light through, but not all of it. Some is absorbed. How much is let through depends on the quality of the glass and on its thickness. Quartz also absorbs some light, but very much less.

While on the subject of quartz, I might mention another one of its properties which leads to some very pretty demonstrations. When reading of light phenomena you will run across the expression "total reflection." One of these demonstrations with fused quartz depends on this total reflection. In Fig. 19 a ray of light is supposed to come from a dense into a less dense medium. The index of refraction is supposed

to be two, meaning that the line *AB* is twice as long as the line *CD* if the lines *OA* and *OC* are of even length. There are two other lines shown: the dotted lines *OE* and *OG*. If I draw the two lines *EF* and *GH* the same way as before and make *GH* twice as long as *EF* I find that the line *OG* almost touches the dividing surface of the two media. If I now draw the line *OK* and attempt to locate the corresponding line on the other side of the dividing line I find that it is not possible to do so. The ray *OK* cannot get out of its medium. In that case there is no longer refraction

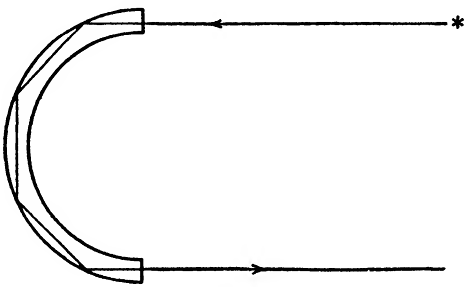


FIG. 20.

but only reflection. The ray is turned back. This will happen every time the ray in the lower medium makes too large an angle with the vertical line, and it happens quite soon if the index of refraction is large. Now, the index of refraction of quartz is very large and so we may expect that there will be total reflection, unless we keep the angle of the leaving ray with the vertical quite small. Based on this fact, a ray of light will follow the interior of a bent quartz rod. Figure 20 shows such a rod. It is bent into a half circle. At one end there is a source of light, indicated by a star. A beam of light is seen to enter the rod. Soon it strikes the wall and, if the conditions were right, it would be refracted and get outside the quartz and

into the air. But the angle with the vertical, at the point where it strikes the wall, is large, and total reflection must take place. It now follows a new path but again it is reflected when it strikes the wall, and so it goes on until it issues at the other end of the rod. Looking at that end of the rod one sees the light as if it had traveled along a straight line and the sides of the rod are left dark because practically none of the light has been absorbed by the rod itself.

Coming back to the X-rays, neither glass, nor rocksalt, nor quartz can be used to analyze them. The trouble is that the wave lengths are too short. They are so short that they pass between the atoms of matter. However, they too, like ordinary light waves, are subject to diffraction and so it is possible to analyze them if one has a diffraction grating with fine enough lines or slots. One might think, as they can pass between the atoms, that this in itself provides a grating, but these atoms are not spaced in any regular way, and so what happens in one spot is counteracted by what happens elsewhere. However, there *are* substances in which the atoms are not spaced in a haphazard way. They are the crystals. It is the very fact that these atoms are placed in a definite pattern which makes that substance a crystal. Any section of a crystal becomes a diffraction grating in which the atoms or molecules form the lands and the spaces between them the grooves or slots.

Coming to the end of this chapter, it seems to me almost as if I heard someone ask, "And what is the use of all this?"

CHAPTER XVII

When the Professor Plays

TO what use can we put this new knowledge is a question which the scientist never asks, or—at least—which he is never supposed to ask. The aim of science is merely the acquisition of knowledge, not its application. The scientist leaves it to others to find some practical use for the new knowledge which he presents to the world. Many years may pass between the discovery of a new truth or a new element and its application to our daily lives. It was a long time—twenty-five years—after helium was found to exist in the sun before it was found to exist on the earth as well. And then there was no use for it at all, and if we could have thought of any use to which we might have put this new element, it would have been a dream only for there was not enough helium in this world, so we thought, to make the dream a reality. Nevertheless, we now fill enormous airships with the stuff. So much for our first ideas as to the usefulness of a new thing.

Aluminum was a material which the professor would show his students, meanwhile keeping a keen eye on the one-inch square piece, to make sure that it was not being pocketed as a souvenir. Its use was confined to the making of small weights for the chemical balance.

Tungsten was of no use at all and few were the people who had even heard of it. Now you are perhaps reading this chapter by the light of a tungsten filament; and during the last great war several nations were

worrying, among other things, about the problem of how to get the necessary amount of this metal for use in high speed steel.

If vanadium were known at all by the average citizen, it was probably because he once heard its name and the word stuck on account of its rhythmic, flowing sound. It was one of the playthings of the professor and of no earthly use to anyone else. Nowadays our automobiles would not be the trustworthy things they are if there were no vanadium in the steel used in their construction.

As to new ideas and theories, they seem to be even more useless than some new-found material of which there is only an ounce or so in the entire world. Take, for instance, the theory of molecules and atoms. What good was it to anybody? The chemist took it up and made it his guide. What chemistry has done for us need not be told here. Everyone knows at least a few things chemistry has done, and by which he personally has profited. There is the periodic table and we know what new materials to look for. There is the theory of the electron and we have the radio. But the scientist cannot trouble himself with the possible application of the new truths he tries to find. He must leave that to somebody else or, if he does it himself, he must wait until he is not busy with his research.

There are generally three steps in the development of the new things we use. First comes the discovery of a new principle, some new or rather unknown law of nature, some new material, or perhaps some new behavior of an old material. Then comes the inventor, the dreamer, who sees with his mind's eye some application which has been made possible by this new knowledge or new material. His product may be crude or costly, and may not yet be a thing which the average man can enjoy. Here is where the engineer

comes to his help with his knowledge of the laws of mechanics, and his ability to design. It may well be that all three are found in one man: the scientist, the inventor, and the engineer, and it is certainly true that very often two of the functions are covered by one individual. It cannot be denied that many scientists have shown great ingenuity and inventiveness in the construction of the apparatus they use, or in the method pursued. However, the scientist uses his inventive ability only to assist him in his work—the unraveling of the mysterious web of the laws of nature.

Some time in the latter part of the eighteenth century, Galvani, a professor of anatomy, hung a frog leg on an iron hook which was fastened in the window casing. The wind played with the frog leg and made it swing against the window frame. Every time this happened, the frog leg would twitch and jerk as if it were still alive. The professor happened to see it. You and I might have seen it and passed on. Galvani stopped, and being a professor, began to play with that frog leg. He did what the wind had done and found that he was just as good at the game as the wind. He noticed that the hook was of iron and the window casing of copper. He thought that this condition of hook and frame might have something to do with the antics of the frog leg and experimented a little. But as he was a professor of anatomy and not of physics, he was not in his element. But he made up for it by revealing his discovery. Volta, a physicist, took it up, and as a result of his experiments he developed a theory which, although now no longer up to date, served the purpose at that time. His theory made him think of a device by which he would be able to get electricity at any time without having to worry about dry weather, cat's fur, or sealing wax. He constructed the *Voltaic pile*. This was a column built up of layer on

layer of copper and zinc discs, separated by pieces of flannel soaked in some acid. The first piece of copper was connected to a wire and so was the last piece of zinc. This was the first wet battery in a rather primitive form. It was soon followed by other and better wet batteries.

Professor Oerstedt of Copenhagen played one day with such a wet battery. His play-room was his laboratory. It so happened that there was a magnet needle on the table where he was playing with the battery. This needle was supported on a pointed rod, and was free to swivel. Oerstedt joined the terminals of his battery; why, I do not know. As he did so, the needle moved. Oerstedt noticed it. You and I might have noticed it too, but we would probably have passed on. Oerstedt stopped. He repeated the thing and reversed it and did all the things with it that he could think of. He found that the needle moved one way when he closed the circuit and another way when he opened it, and he found further that just as an electric current affects a magnet so does a magnet affect an electric current. He would pivot a loop of wire and arrange it so that current could be fed to it, in whatever way the loop happened to be standing. He found that the loop would turn if it were approached by a magnet, and, more than that, the mere approach of the magnet would set up an electric current in the loop. Best of all, he let the world know what he had seen, for scientists make no secrets of their discoveries. Many others took up the new game and now we have our dynamos and electric lights and telegraph and telephone.

It was soon found that there is an intimate connection between electricity and magnetism. Not only did a current affect a magnet or a magnet affect a current, but a wire through which an electric current

flowed could be made to act as a magnet. All that was necessary was to arrange the wire in the form of a coil or helix. Such a coil will attract a piece of iron, just like a magnet. This led to the electro-magnet. Heretofore all magnetism had to be studied by means of permanent magnets and even the strongest ones in existence are but weak as compared with an electro-magnet of reasonable size. Now, this is the principle of the dynamo: move a closed circuit of wire (preferably copper) toward a magnet and you get an electric current. Then use some of that current and send it through the wire around a piece of iron and you get an electro-magnet, which will furnish you the necessary magnetism to get the current to make the magnetism, etc. A very pretty circle. The thing sounds unreasonable, for you must have the magnet in order to get the current, and you must first have the current to make the magnet. And yet, this is exactly the way it works in the electric light plant when the dynamo is started. There is just one little bit of difference between the actual conditions in that plant and those which I have been describing to you.

The direct current dynamo has a number of electro-magnets placed in a circle. That is, they are magnets when the current generated by that dynamo flows through them. However, when the machine stands still, they are merely pieces of iron with some copper wire wound around them. They could produce no current in the armature if nature did not come to our assistance. The assistance she gives us is this: that *any* piece of iron or steel is a magnet, though generally so weak that we cannot notice it without refined measurement. A magnet needle, properly supported, points toward the magnetic pole. If it is so supported that it can move in a horizontal plane only, it must, of

course, remain horizontal and it does not really point to the pole, but only in the horizontal direction of the pole. If, however, it is supported in such a way that it is free to move in any direction, either horizontal or vertical, it will point to the actual location of the magnetic pole. Conversely, any piece of iron or steel held in the direction pointing to the pole becomes a magnet. This magnetism will be stronger the more nearly the direction of the piece of iron points toward the magnetic pole, and it is at its weakest when its direction is at right angles to the best position. Any angle between the two extremes will give the piece of iron some degree of magnetism, however little it may be. We make use of this condition when we start the dynamo. At first the magnets are very weak, and they produce but a very weak current in the armature. We lead this bit of current through the wires around the magnets, and so strenghten them a little. This causes a little more current to flow through the armature, and this in its turn strengthens the magnet still more. This goes on until the current has become of the desired strength or voltage, when we make a somewhat different connection of the wires, which will allow just about enough current to flow to the electro-magnets, while the rest is sent to your home or to the factory, there to be used in any of the many ways of which you know.

Perhaps the prettiest illustration of how magnet and current affect each other is the telephone. The original telephone consisted, just as the present one, of a transmitter and a receiver; but these were alike, so that the telephone system consisted of two receivers, connected by a wire. The speaker would hold one instrument to his mouth and the listener would hold the other one to his ear. Of course, I am speaking of the experimental arrangement and not of the system which

was used even in the earlier days of telephonic communication. Each of the two receivers had a permanent magnet, around which part of the connecting wire was wound. In front of the magnet was a diaphragm, which was set in vibration by the sounds the speaker made.

Those who have not studied sound vibrations are apt to think, if they think about it at all, that one can represent them on a piece of paper as a nice smooth snake line, and, in fact, this is the case with some sound, such as that made by a tuning fork. However, practically all sounds we hear are not so simple. They consist of a number of sounds mixed together. A musical note consists of the basic note and its harmonics. These harmonics are other sounds of which the number of vibrations per second is a multiple of the base note. If, for instance, the base note is *C*, then the harmonics are the *C* one octave higher (double the number of vibrations), the *G* a fifth higher again (three times as many vibrations), the *C* two octaves higher (four times as many vibrations), and others. Some or all of these vibrations may be present in the tone we hear. They may be strong or weak, and the presence of these harmonics and their relative strength give us the impression of the color, the timbre, of the note.

If we play such a note in front of the diaphragm which is provided with a stylus, we can make a picture of these vibrations on a piece of smoked paper. We can make a magnified photograph of it, and we will then see a line which goes up and down and which makes one think of the waves of the ocean, with small waves super-imposed on the larger ones, ripples on the small waves and smaller ripples on the big ones, and—partly quoting a well-known verse—"And so ad infinitum."

There is a very nice way to demonstrate this in the lecture room. The note is played in front of a gas flame, which bobs up and down according to the nature of the tone played. Its image is projected through a system of lenses on a mirror with four sides. This mirror revolves at high speed so that no two vibration images fall on the same spot of the mirror. The human eye is slow. It retains an impression for some time, about one-eighth of a second. The vibrations appear on the mirror at a much faster rate than eight a second, so that our eye is still seeing the first vibration when the second and third, and perhaps more, appear. We seem to see a number of these vibrations side by side, and thus get a very good idea of what they are like. If the note is a musical one, there are as many complicated vibrations per second as are caused by the base note. If we play a chord we find the same, though the vibrations are more complicated because each of the notes of the chord brings its own harmonics with it. But if the sound made is not a musical note, the vibrations do not recur with such regularity and the thing seems to be hopelessly mixed up. Our vowels, when pronounced in the same key, differ only in the harmonics.

When we speak into the telephone transmitter, we cause the diaphragm to vibrate. If the pitch of our voice is such that the base note makes four hundred vibrations, we must not think that the diaphragm goes in and out four hundred times a second, for each of these movements may be very complicated, due to the harmonics. It is true that there are four hundred main movements but each one of them is interrupted and changed in many different ways. However, the effect on the magnet back of it is that its armature (the vibrating diaphragm) approaches it and goes away from it a number of times. Each time it ap-

proaches, it causes the magnet to be a little stronger, and each time it goes away it makes the magnet a little weaker. The amount of this strengthening or weakening depends on the amount the diaphragm moves. This change of strength of the magnet causes a corresponding change in the current in the wire; that is, if the diaphragm approaches, it causes a current to flow in the wire in a certain direction, and when it goes away from the magnet it causes a current to flow in the opposite direction. This current must flow through the wire around the magnet in the receiving instrument, and there it strengthens or weakens the magnet, thus causing the diaphragm to be more or less attracted. The net result is that this diaphragm vibrates in the same manner as the one in the transmitter, and thus reproduces the sounds made there. One look back of the switchboard of a telephone exchange will convince you that the present system is much more than the one I described just now, but the underlying principles are still the same.

The average citizen is apt to ask what good it does him if some professor discovers a new phenomenon or some new material. He does not think of Oerstedt or Faraday when he steps into the street car or picks up the telephone. He does not realize that one of these discoveries may change the current of his life a few years hence. For that matter, neither does the scientist who makes the discovery, or, at least, not as a rule. It is true, too, that some of these discoveries, taken alone, may not lead to anything the average citizen appreciates; but, considered as one link of a chain, each one may be of the greatest practical importance later on. For instance, what practical use can one make of the fact that a glowing wire makes the air in its neighborhood conductive? And yet this fact, combined with some others, enables us to

hear in New York the strains of a concert played in San Francisco.

The hot wire makes the air conductive because it emits some positive and negative particles, the ions and electrons. If it were possible to hold the ions back, we would have a constant stream of electrons. As it is, the ions and electrons combine again as soon as they are away from their source. This separation of the ions and electrons is made in the tubes you use in your radio set. The hot wire is, in this case, the filament of the tube. Opposite this filament there is a plate which is electrically charged. This charge is positive. When we say that a plate is charged, we mean that it is connected to some source of electricity, so that a current will flow if there is also a connection to the opposite pole. In this case the plate is connected to a battery, but the connection to the other pole of the battery is wanting, so that, ordinarily, nothing happens. Conditions change as soon as we turn the current on which lights the tube. If there were no plate, the filament would emit positive and negative particles and they would combine again, but as the plate is positively charged, the negative particles are attracted by it and do not return to the filament.

In the early stages of radio development, the plate was not charged from a battery but obtained its charge from the bit of electricity caught by the antenna. This electricity did not come to the antenna as a uniform current—such as we get for our electric light—but was fluctuating. It was now stronger, now weaker; in short, it showed the same fluctuations we met in our primitive telephone set. The fluctuations were caused by the voice or the musical instrument at the sending end. As the plate was more or less charged by this bit of incoming current, more or less electrons would be caught by it and, as a consequence, more or less current

would flow. This fluctuating current was led to the head phones and there reproduced the sound made at the sending station.

To be perfectly honest about it, even this simple arrangement was not the original one. At first no tube was used. The radio receiver depended on a peculiar quality of some crystals, in that they would pass current in one direction only. The incoming waves are of the alternating kind. One can make a graphic representation of them by drawing a snake line and then drawing a straight line so that half the oscillations are above and the other half below it. We had the same condition with the telephone, and the diaphragm followed these alternations. Unfortunately this cannot be done with the alternations which come in over the antennae. There are too many of them per second. Take, for instance, a concert which comes in over a 500 meter wave length. As these waves come to us with a speed of 300,000,000 meters (or 186,000 miles) per second, which is the speed of light, the number of waves per second must be 300,000,000 divided by 500 and this is 600,000. Now, no self-respecting diaphragm would attempt to make that many forward and backward movements in one second. However, the crystal has wiped out all the little curves on one side of the straight line, and the remainder now run all in the same direction, so that the effect on the diaphragm is merely to draw it a little closer to the magnet. As a result, nothing happens so long as there is nothing to vary the strength of this current.

The current which comes over is not one which can be represented by a nice even snake line. There are the same irregular ups and downs which we found existing in telephone transmission. These irregularities are caused by the voice or the instrument at the sending end, and they are of a frequency to which the

diaphragm can respond. These irregularities cause the diaphragm to vibrate and let us hear what was said at the other end of the line. We have here a complete radio receiving set, but the amount of current which comes in over the antenna is so extremely small that it speaks well for the listener and his head phones that he hears anything at all.

The charged plate opposite the filament does the same as the crystal. The plate is charged by the incoming current and this current is, as we have seen, of the alternating kind. It charges the plate alternatively positively and negatively, but it attracts the electrons only when it is positively charged, because the electrons themselves are negative, and so it allows current to flow in one direction only, just as the crystal did. Here, too, we deal with extremely small quantities of electricity, though somewhat greater than we got with the crystal. The next step was to increase this amount of current, or rather, to use this small amount to open a door through which a greater amount could flow. This is done by the grid.

The grid is a network of wires placed between the filament and the plate. It receives the incoming current. The plate itself is no longer charged by this incoming current but by a battery. It attracts the electrons from the filament all the time but it is too far away from the filament to have much effect. The grid, being charged by the incoming current, allows the electrons to pass to it and on to the heavily charged plate, whenever it becomes positive. Whenever this happens a current from the battery flows through the system. The incoming current has merely served to turn on the switch which allows the current from the battery to pass. Or, to put it another way, it has opened the valve which allows the steam to pass and drive the engine. This current can be passed on to a

head set or a loud speaker, or it can be used to energize another grid in a second tube. In the latter case it turns on a larger valve to admit steam for a more powerful engine, and this engine may be used again to turn a still larger valve, etc.

This turning on of a series of valves or switches is nothing unusual. Whenever you read of the President opening a World's Fair or starting some great public improvement by simply pressing a button at the White House, you may imagine such a system of increasingly larger and larger valves. The number of ways in which this may be done is legion, but here is one of the possible arrangements. The President presses a button which sends an electric impulse across the country. This impulse is no stronger than that which passes when the telegraph operator presses his key. It energizes a small magnet at the far end, and this magnet closes a local circuit which in its turn operates a stronger magnet, which closes the circuit of a motor, which turns the valve which starts the engine. All very much like the house that Jack built.

And so, you see that ionizing air by a hot wire was not all useless play after all.

CHAPTER XVIII

Full of Energy

WHEN I eat a piece of apple pie at Child's restaurant I enrich my system with so and so many calories. The exact number has escaped me and I do not have the menu card before me, but I'll call it two hundred, because that number will do here as well as any other and the size of the piece of pie is never specified, anyhow. I do not know exactly what I can do with these two hundred calories or what they can do to me, but I presume it means that if the piece of pie is perfectly digested, completely assimilated and entirely oxidized by the oxygen of the air I breathe, then I'll be warmed up to the extent of two hundred calories, or that I'll have received the power to do work equivalent to that amount of heat, or, perhaps, some of this and some of that. If it all goes to heat, my one hundred and fifty pounds will rise in temperature about one and a half degrees, or possibly a little more, because my specific heat may be a little less than that of water. Nature has taken care that my temperature cannot rise, so this heat will be stored in some form or other and will be available at some future time. On the other hand, if the piece of pie has been transformed directly into energy, it means that now I shall be able to lift two hundred pounds to a height of seven hundred and seventy-seven feet or its equivalent, for, as you know, one calory is equivalent to 777 foot-pounds.

By carefully weighing every bite we eat and every sip we drink, and then doing some little stunts of multiplication and addition we can know exactly how

much energy we put into our bodies, or at least we are told that we can know it in this manner, and for people who believe in Abramson's system of diagnosing and healing by electronic vibrations, and for some others, this method of keeping track of our store of health and energy is just about as good as any other. There are, perhaps, a few other things which we might take into consideration. For instance, if we drink two quarts of ice water a day, we must raise the temperature of that water from 32 degrees to about 98 degrees (our body temperature). This requires 66 calories per pound or pint and, therefore, 264 calories for the two quarts. This shows that a piece of pie is more than counteracted by two quarts of ice water. But if we take some hot coffee instead of the ice water we can get along with less apple pie.

However, and notwithstanding all the nonsense which can be built on the idea of shoveling calories into our bodies, the fundamental truth cannot be denied that our food, wholly or partly, is transformed into heat, or energy, or both. This truth is based on the fact that chemical combination is accompanied by generation or absorption of heat. We are thoroughly familiar with some cases of generation of heat by chemical combination. The use of our fuel is a case in point. There we burn some substance, which is merely a short way of saying that the fuel combines with the oxygen of the air. We first provide the proper temperature, for the oxidation does not take place until such a temperature is reached. Later on, the burning of the fuel raises the temperature of the rest of that fuel so that it, too, can burn. We start the game by burning some kindling, and we bring this kindling to the proper degree of heat by burning some paper under it. In order to oxidize the paper we must first bring it up to a certain degree of heat and we do this by holding a

flaming match under it, for paper does not oxidize at the temperature of the room. This match is provided with some chemicals which start to burn at a relatively low temperature, and so all that is necessary to begin is to rub the match and cause it to warm up by friction. Again the house that Jack built.

This last story makes it seem as if nothing will burn unless something else burns first, the only exception being that of the chemicals of the match, and even there we had to provide some heat to start the chemical combination. However, if we look around a bit we find many instances of chemical combinations which take place without the application of heat. Rusting and corrosion are instances of this. Even coal will burn without being ignited, but the burning takes place at such a slow rate that the heat is carried off as rapidly as it is generated. It may happen, however, that the heat cannot escape—for instance, when the coal is heaped up in a large mass. When that is the case, the heat may become greater and greater until, finally, the heap is set afire. This is called spontaneous combustion.

Such spontaneous combustion can be demonstrated at will by a simple experiment. Dissolve some sulphur in carbon disulphide and let the solution drip through a piece of filter paper. Then take the wet piece of paper and spread it out. The carbon disulphide evaporates very quickly and leaves some of the sulphur behind on the paper in a very finely divided state. Suddenly this sulphur flames up. It was this condition of being finely divided that caused the spontaneous combustion, because there was so much surface exposed to the air. Dividing a piece of material into many smaller pieces increases its exposed surface. A one-inch cube has a surface of six square inches, but if we divide it into eight cubes with sides of a half inch, we give it a

combined surface of twelve square inches. Coal in powder form, or flour, or any other oxidizable material in a finely divided state, is subject to spontaneous combustion.

We have drifted from our subject, which was that chemical combination leads to the development of energy in the form of heat. However, this is not always the case. There are substances which develop heat when they combine and there are others which require heat for their combination. The amount of energy delivered or required varies for the different compounds and may be very large. As an example, take one pound of anthracite coal, which will deliver 12,000 B. T. U's when combining with oxygen, notwithstanding that part of this one pound is ashes which does not contribute to the energy delivered. A pound of soft coal does even better, often going as high as 14,500 B. T. U's. There is then enough energy stored up in this pound of material to lift 12,000 pounds to a height of 777 feet. Think, then, of the energy in a few grains of gun powder. It is natural to ask what it is that gives so much energy to a seemingly lifeless thing. How was this energy stored and kept in bounds, and just what happens when it is set free? We do not always realize that something very interesting must take place when a piece of coal burns and even when it does not burn; we are so used to these things that we do not give them thought, and take them for granted, just as we take for granted most of the miracles which happen before our eyes every day of our existence.

However, once in a while something occurs, something new, and we wake up and begin to ask questions. This was the case when radium was discovered. That it, too, had some energy stored up was not so strange, but here was something entirely different from the processes with which we were familiar. If we light a

piece of coal it burns, but when we keep it cool or away from the air it remains a piece of coal and entirely inert. Not so with a piece of radium. Keep it cool and in a vacuum and it keeps on giving out energy. It is not affected by heat or cold, and is entirely independent of its surroundings. Combine it with some other element and it will continue to give heat at the same rate at which it would have done if it had been left alone. It is not possible to increase or diminish its rate of giving out energy. A piece of coal by itself does not give energy. It does so only when it combines with something else. It is really not quite correct to say that a pound of the material has so and so many B. T. U's. We should say that it delivers this amount when it combines with oxygen. If it is made to combine with something else it may deliver a different amount. In this way it resembles the piece of apple pie. That piece of pie may deliver 200 calories to one person, but to another it may not give anything but indigestion. Left alone, it shows no calories at all. Radium, on the other hand, delivers so many calories per gram per hour, rain or shine.

And so, it is not to be wondered at that the appearance of radium on the stage made every scientist ask what it is that gives radium the power to act spontaneously; and, what is more, to do it at a rate which shows that it must have inherent energy to an amount incomparably much greater than anything hitherto known. Until the advent of radium the world had known energy in various forms, but the energy displayed by radium could not be classified with any of them. We knew of the potential energy of a weight hung from a rope; cut the rope and the weight can be made to do work by the gravitational attraction, or, for that matter, it can be made to do it without cutting the rope. We knew of the potential energy of a

wound-up spring; here we were dealing with molecular stresses of the material of the spring. We knew of the live energy of a body in motion and read about it in the papers when one locomotive struck another. We also knew of the hidden energy we call heat, and of the energy of gases, and we knew that both were the energy of molecules in motion and, therefore, of the same kind as that of the moving locomotive. We were also familiar with the energy coming from chemical reactions, and there we had something different from the others, for this energy was not due to properties of the mass of a body, such as the suspended weight, or even of its molecules, such as is the case with a spring or a gas under pressure, but of the atoms and their properties. The action of radium, however, could not be attributed to gravitation, to stress of molecules or even to chemical affinity. A new chapter of blank pages was presented to the scientific world.

The title of the new chapter was written but the pages were blank. The title was: ABOUT THE ENERGY STORED UP IN THE ATOM, for it was clear, almost from the beginning, that there must be something peculiar to the atoms of radium which enabled this material to dispense energy continuously and without any outside stimulant. When it was discovered that radium would gradually change into another element of lower atomic weight, this idea became a certainty. It has been found that heat given out during the process of disintegration of a piece of radium is several hundred thousand times as great as that which can be derived from a piece of coal of the same weight. However, this is not all of the energy contained in this element. The heat given out is only a by-product of the process which is going on. Part of the process is the shooting off of alpha, beta and gamma rays. The alpha rays are atoms of helium, or rather the ions, and they have

appreciable weight, their atomic weight being 4. The atomic weight of radium is 226, so that by the time radium has been converted into its emanation it has lost almost one-fiftieth of its weight. As we know, it does not stop there, for the emanation changes into something else again and this process goes on until the final product, lead, has been reached. Lead has an atomic weight of about 207 so that, at the end, 226 units of radium have been transformed into 207 units of lead. The radium has lost 19 units or about one-twelfth of its weight. This lost weight is helium, which has been shot off as alpha particles. The alpha rays have a speed of more than ten thousand miles a second, and some of them as high as twenty thousand, but we'll be modest and confine ourselves to the lower figure.

It is interesting to compare the amount of energy required to give these alpha rays this speed with some of the things with which we are familiar. We may imagine a piece of radium weighing twelve pounds, for it costs no more to make it twelve pounds than to imagine it as a fraction of a gram. Let us see how much energy such a piece would have if it were moving with the speed of an express train, say sixty miles an hour, and also with that of a shell fired from a gun, say 2,500 feet a second. There is a very simple formula, with which anyone dealing with such things is acquainted, and which allows us to calculate the amount of energy possessed by a body in motion. The result of the calculation is expressed in foot-pounds. In this form the result can be very easily imagined. If we should find that the energy is 500 foot-pounds, then we know that the amount of work which could be done with this energy is the same as that which would be done by a weight of 500 pounds falling one foot or 100 pounds falling five feet.

Applying this formula we find that a twelve-pound piece of radium moving at a speed of sixty miles an hour has an energy of 1,452 foot-pounds. If it moves with the speed of a projectile the number of foot-pounds is 1,171,875, or, as it would generally be indicated in order to avoid unwieldy figures, 586 foot-tons. The energy represented by the one pound of alpha rays will have to be written in foot-tons, and even then I shall not be able to avoid formidable looking sums. This number of foot-tons is 1,393,920,000,000, an absolutely inconceivable amount. Before these alpha rays can come to rest they must have done this amount of work. Fortunately for us, this energy is not let loose at once. Half of this amount would be released in the first eighteen hundred years, half of the remainder in the next eighteen hundred years, and so forth. The fact that, at the present, we are not dealing with pieces of radium weighing twelve pounds provides another factor of safety.

Madame Curie was recently presented with one gram of radium, which is about the fifty-four-hundredth part of twelve pounds. If she, or anybody else, could suddenly release all the alpha particles which ultimately will be released, there would be let loose on the world the terrific amount of 387,000,000 foot-tons of energy.

The reason why this amount becomes so formidable is that we are dealing here with enormous speeds and the further fact that the amount of energy possessed by a moving body is proportional to the square of its speed. Whereas a projectile shot from a gun may have a speed of as much as half a mile a second, the speed of an alpha particle is more than ten thousand miles, or twenty thousand times as great as that of the projectile. Its energy is therefore four hundred million times as great as the same amount of weight moving with the speed of the projectile.

Let us compare this amount of energy with what we could get from a pound of soft coal. As a pound of that material will give us 14,000 calories, we could convert this into 14,000 × 777 foot-pounds or 5,439 foot-tons of energy, provided that nothing were lost in the conversion. This comparison naturally leads us to think of the enormous amounts of energy which would be at our disposal if we had some means to control the process, and if there were enough radium available to use it in industry. This latter difficulty is not as great as it seems at a first glance. It is true that there is not enough radium to use it for any other purposes than experimentation and medicinal uses, but there is another element which has more energy stored up in its atoms and which can be had in reasonable amounts and at reasonable cost. This element is uranium. Uranium has an atomic weight of 238 or 12 more than radium, so that, by the time it has converted itself into lead it has lost 31 in atomic weight. This is 63 per cent more than the loss of radium, so that the amount of energy we found for the one gram of radium must be increased by 63 per cent. I will refrain from putting the figures down; they are too large to mean anything, except that the amount is very large. All we have to do now is to find a way of speeding up the process of disintegration of uranium, for it would not do at all to let nature take its course. Uranium loses half its weight in several billion years and this is enough to make patience a useless virtue. So far, no way has been found to speed up nature's process, but this does not prevent us from dreaming about what would happen if we could do it.

It is a sorry thing that we cannot think of the good we might derive from some new material or some new force without wondering if its first use is not going to be another means of destruction in war. With such

forces as we meet here this wondering is almost a dread. If, sometime, all of humanity learns to get along without war, then the discovery of some means to control the intra-atomic forces will be the greatest boon ever bestowed upon us, for it will put in our hands unlimited power and inexhaustible energy. Heat, light, industrial power and means of locomotion will then be available in unlimited amounts and there need be no fear that some time we will come to the end of our supplies. A gram of uranium stored somewhere in our automobile will be sufficient to run it year upon year. A shovelful would be enough to warm the house for I do not know how many winters. In short, the wildest fancy would not do justice to the things we could have or do.

This intra-atomic energy is not peculiar to the radio-active elements. It is found in all elements with the exception of hydrogen. What is peculiar about the radio-active ones is that some of that energy is set free without any apparent cause or without any outside help. No other elements have this gift, if I may call it that, or if they do have it they have it in such a small degree that it has not yet been observed. To the contrary, it takes a great deal of power to break up an atom, though this has been done in a small way. A few atoms of nitrogen have been broken up and part of them projected as hydrogen. There was not enough of it to say with certainty what the remainder was, though it is believed with some reason that what was left was carbon. I can almost hear someone say, "Why call nitrogen an element if it can be split up into two other kinds of materials? An element is a material which cannot be decomposed, or which, in other words, is not composed of other materials." This would have been a good enough definition before radium was discovered, but now we will have to say that an element

is a substance which cannot be decomposed by chemical means, just as we can say that a molecule is a particle which cannot further be divided by mechanical means. We have already made the acquaintance of the decomposition of atoms when we spoke of electrons and ions. They are parts of atoms, and we cannot say, therefore, that atoms are indivisible, as their name would indicate. However, they cannot be divided by chemical means. They combine with other atoms as units and when such a combination is split up they reappear as individuals. They do not come out in pieces, but as whole atoms with all the qualities they had when they entered into partnership with other atoms. Electricity may split up an atom in a certain way, as we have seen, and there are certain atoms which disintegrate, though neither electricity nor any other means seems to have any influence on the process.

When an element is ionized it loses an electron, or perhaps more than one, but it makes no difference what the element is, the electrons which come from it are always the same. The remainders of the atoms are not the same; they are the ions, and these ions differ as much as the atoms of which they are a part. It is natural to suspect that these ions may, after all, be an assembly of simpler and similar parts. This assumption has been found to be correct. Of course we must never forget that science gives no final verdict. It merely says that, according to an overwhelming amount of evidence, atoms are built up out of electrons and other particles, which have been called protons. There is quite some difference of opinion among scientists as to how the atom is constructed out of these two constituents, but all agree that electrons and protons are the building stones of the atom. The cement is electrical attraction. What causes this attraction between

dissimilar electrical charges is still a deep and dark mystery and is likely to remain a secret forever.

When we try to explain a thing we search for something simpler than the facts we wish to explain. For instance, we see a number of different machines in a factory, all going through more or less complicated motions, and we ask what makes the wheels go round. We discover the steam engine and see the connection between it and the various machines. Here we have one cause for a number of effects we had noticed. However, right away we are confronted by the question as to what makes the steam engine move, and someone explains to us that it is the pressure of the steam behind the pistons. This makes us ask why the steam, which, after all, is only water vapor, should be able to exert this pressure and we are told that this pressure is nothing but the effect of moving molecules bumping against the piston. We started with a number of machines, each with some complicated movements, and we have arrived at the simple movements of the molecules of a gas. However, the human mind cannot stop, and must ask still more questions. What causes the molecules of the gas to move? The answer is heat. But this is no answer at all, because heat, as we know it, is movement of molecules, and so we must go still further and ask what made this heat; and we are told that it was the combining of the fuel with the oxygen of the air. And what made them combine? Here we must descend into the lower regions of hypothesis, or, if you wish, conjecture. We will have to explain it by the peculiarities of the atoms and those we must explain by the behavior and the properties of their constituent parts. Going still further down we come to the electrical nature of the electron and the proton, and there we have to stop—not only because nothing more elemental is known at the present time, but also,

and especially, because it is difficult for us to imagine anything simpler than just one force acting on only two different materials. And yet, there seems to be some evidence that some time in the future we may do away with the two materials and explain everything by just the one force.

CHAPTER XIX

About Bowling Balls and the Solar System

I HAVE in my hand a bowling ball. It is eight inches in diameter. It is beautifully polished and shines like a mirror. I intend to use it to make a replica of this earth on which we live; I'll build up the mountains and carve out the sea and the rivers, and, perhaps, build cities. I'll begin with America, outlining its contours and then progress to the building of the country in relief. Everything must be made in the proper proportions, and so the first thing to do is to find the unit we must use to measure and construct the various items. The earth has a diameter of about 8,000 miles, so that 1,000 miles of that diameter correspond to one inch of the diameter of my ball. One mile is therefore one-thousandth of an inch.

Now let us start with the highest mountain in the United States, Mount Whitney. It is practically 15,000 feet, or three miles, in height, so that we must build up to a height of three-thousandths of an inch to show this mountain in the proper proportion to the size of the earth. Three-thousandths of an inch is the thickness of the average grade of writing paper. As to the diameter of the base, I do not know just how much it is, but I can look it up. However, as the mountain is part of a range, it does not matter very much what I make it as the foot will melt into the rest of the mountains around there. If no one objects, I'll make it thirty miles, which means that I must cut out a piece of paper one thirty-second of an inch in diameter. I paste this to the ball and shave it down so as to give it a little the shape of a

cone and let it go at that. There is one thing I must not forget: I may not use much glue, for even a little bit will raise the height of my mountain another half mile or so. Having done all this I can proceed with the smaller hills in the chain, gradually coming down to the plateau, which is about one mile in height. I can represent this by pasting a piece of tissue paper over the place where this plateau is to be.

Next in order is the ocean bordering on the United States. This time I must cut away some of the material of the ball. The greatest depth of the ocean in that part of the world being about two miles I must shave the ball, where the ocean is to be, to a maximum depth of two-thousandths of an inch, which is the thickness of a human hair. Of course, near the shore the depth is much less. We will also make the great lakes, which are several hundred feet in depth, and for them I must shave the ball down a few ten-thousandths of an inch. Then there are the rivers. Let us start with the Hudson which is a mile wide at New York City. It is some forty-five feet deep in the channel there. This means that we must dig a canal in the ball one-thousandth of an inch wide and almost a one-hundred-thousandth of an inch at the maximum depth.

While we are at New York we may try to show some of the large buildings and, if we succeed, we may then try some of the smaller ones, gradually building up an entire city. Let us begin with what is now the tallest building, the Empire State. It is a little over 1,200 feet in height, or less than one-fourth of a mile. Its width is about four hundred feet, so that I must cut out a piece of paper one-fourth of the thickness of tissue paper and give it a width of about one-twelfth of a thousandth of an inch. I confess my inability to do so, and we will have to give up the idea of building New York on the ball for lack of the proper materials and skill.

However, I can imagine that I have finished the ball and that everything on the earth has been properly represented. I am supposing that you did not see me make my earth and that consequently you do not know any of the details of the ball. You are requested to take a stand twenty-five feet away from me while I show you my earth, and tell me what you see. Of course, you cannot see such little things as the Hudson River, and I doubt whether you will notice the Great Lakes, but there is just a chance that you may discover the ocean and, if you have good eyes, you may see Mount Whitney. I'll show the ball also to somebody else, but this time I'll ask him to go a hundred feet away. This man sees the ball, but to him it is just a ball and nothing else. If I throw a strong light on it he may see that the polish is not quite perfect, but he cannot say what is the cause of this imperfection. The third man to whom I show my handicraft I place at a distance of a mile and a half. Of course, it is extremely doubtful if he can see me, much less the ball I have in my hands. However, I give him a good telescope, and this will enable him to see the ball. But how much of its detail can he observe? I come to the conclusion that, so far as he is concerned, I might have saved myself the trouble of pasting things on it or carving pieces out of it.

You may think that it is perfectly ridiculous to ask a man to look for fine detail on an eight-inch object, a mile and a half away, but this is just what a man, placed on the sun, would have to do if he were asked to describe the things he saw on our earth. Mountains and seas would have disappeared and there would be nothing left but a polished ball, and to see even that much he would have to use a powerful telescope. Just figure it out for yourself, and you will find that an eight-thousand-mile object at a distance of 93,000,000

miles (the distance of the sun) looks exactly as large as an eight-inch object at a distance of a mile and a half.

In the rural districts of Europe it is customary to indicate distances between cities or villages by the time it takes to walk from the one to the other. If you ask how far the village *A* is from where you are, you may get the answer, "About three hours," meaning that it will take you about three hours to walk there. The accepted rate of walking is three and a half miles an hour. This is not such a bad way of rating distances when there is only one way of traveling—namely, afoot. It saves you the trouble of figuring out for yourself how long it will take to get there. We might do the same thing here, except for the facts that nobody walks from one city to another and there are so many other ways of getting about. We would have to indicate how, and at what speed, we intend to travel and that is exactly what we are doing now. However, where there is only one method of going from one place to another, this way of expressing distances is quite acceptable. Now, the only way we have of getting from one star to another is by means of a ray of light. There is no other mode of transportation, and so we may follow the European peasants' method and indicate distances by minutes, hours, or years. For instance, the moon is one and one-third seconds away from us. The sun is at a distance of eight and one-third minutes, and the nearest fixed star four and a quarter years.

It may be interesting to see what our earth looks like as viewed from this nearest star. Our new way of stating distances gives us an easy way of indicating what our earth would look like to a man on that star. As the star is 264,000 times as far from us as the sun, this earth will seem to have a diameter 1/264,000 of what it seems as seen from the sun; or, what is the same thing, 1/264,000 of the size of my eight-inch ball

viewed from a distance of one and a half miles. In other words, I hold my ball at a distance from you of 396,000 miles and ask you what you see. The answer is easy: you don't see anything. We will not investigate what our earth would look like seen from a star a hundred-thousand years from us. The result would be too humiliating.

It is not very agreeable to appear in the eyes of the world as being so insignificant that one is not noticed at all. When such a thing happens among us mortals we are apt to point to some member of our family who has made a mark in the world and say, "He is one of us." Well, we have such a member in our stellar family—the sun itself. Our sun should make a fairly imposing appearance as seen from that star. We can easily figure out how large it must appear if we know its actual size, as we do. The sun is about 110 times as large in diameter as our earth and it therefore appears, to someone somewhere in the universe, as our earth would appear when seen from a distance only one one-hundred-and-tenth as great. Our earth looks like an eight-inch ball seen from a distance of 396,000 miles, and the sun will therefore look like an eight-inch ball as seen from a distance of only one-hundred-and-tenth as much, which is 3,600 miles. We will have to agree that even our sun does not seem to be very much of a sun to a man on the star—the nearest star at that.

We have one consolation, one balm for our hurt pride: the star does not seem any larger to us than we do to it. If there are little earths circulating around that star, we are not aware of them; they are too small to be seen with the best instruments we can construct.

There may be millions of these little earths, each inhabited by millions of people who are wondering just as we are. Are such things forever to be hidden from us? We cannot say; but this we know, that there

are many things which at one time were as much of a riddle as our present mysteries. Gradually new instruments were invented, new methods developed, which brought to light what was dark before. Only those few stars were known which could be seen with the naked eye. Then the telescope was invented and the number of stars was increased from a few thousands to many millions. Now the camera shows us stars which the eye cannot see, even when armed with the strongest telescope. But there are stars which do not emit light and cannot be seen by the eye of the camera; yet we know that they exist and where they are. Though we cannot see them we can see the effect they have on other stellar bodies, for they are all subject to the force of gravitation. If such a dark star is somewhere near another star, one which we can see, we may notice this effect. The two stars attract each other and modify each other's orbit. Not only can we come to the conclusion that there must be a star which we cannot see, but, if the orbit and the weight of the visible star is known, we can calculate the position, orbit and weight of the invisible one. That this is so was illustrated in a striking manner by the discovery of the planet Neptune.

For a long time Uranus had been the farthest known planet. It had been discovered by the famous astronomer, Herschel, in 1781. Then in 1846 Neptune was discovered, not by seeing it, but by noticing certain effects it had on the orbit of Uranus. Complicated mathematical calculations led to the conclusion that there must be another planet, and the exact position of this new body was predicted. The honor of the discovery should be divided between Adams, the Englishman, and Leverrier, the Frenchman. Perhaps I should say that each one is entitled to the full honor, for the two worked independently of each other.

Adams asked the observatory at Cambridge to look for his new planet, but the instruments there were not powerful enough to find it. Leverrier asked the observatory in Berlin to make search and one of the observers there, Galle, found the new member of the solar family where Leverrier had told him to look for it. This story was recently repeated when the latest addition to our planetary system was discovered.

The discovery of Neptune very much resembles a trial in which a man has been condemned on circumstantial evidence only, but where the condemned one later confessed his guilt. Such an occurrence would strengthen our faith in circumstantial evidence; and, in like manner, the story of Neptune has strengthened the popular faith in the processes of the scientist by which he concludes the existence of things unseen, even when no positive proof, like a confession, can be obtained later on. Much of the present day knowledge of the universe depends on this kind of circumstantial evidence. The deductive method is not confined to astronomy; it is used to an even greater extent in the science of physics, and this must necessarily be so, for in physics we deal constantly with bodies too small ever to be seen. There is, for instance, the theory of atoms, and electrons, and protons, and whatnot. None of these things has ever been seen and, probably, never will be seen; yet, no one familiar with the merest outline of the science of physics or chemistry doubts for a moment that there are such things. Those people who have penetrated a little further are sure that they know some of their properties, their size, and weight, and their general way of behaving in regard to their neighbors.

Perhaps the strangest thing which has been found out about these extremely small things is that each little atom is a counterpart of our solar system. It is

fortunate for us that we have discovered that there are stars the light of which needs several hundred thousand years to reach us, for this gives us a chance to philosophize about what our solar system looks like to them. We know that to the people on such a star we are as invisible as the atom is to us. The reason why our solar system seems so large and important to us is that we are in it. If only we could get into an atom we might see as many interesting and wonderful things as we have found in our solar system.

Therefore, let us go inside an atom and look around.

CHAPTER XX

Inside an Atom

WE have several atoms to choose from for our visit. I do not mean that we can choose between an atom of gold or one of lead or, perhaps, one of hydrogen, but that we can choose the style of atom we wish to see. Different architects are apt to have different styles for the buildings they design, and so have different scientists for an atom they design. Let us first visit one as designed by that great scientist and experimenter, J. J. Thomson. His atom is no longer the fashion, though it held the center of the stage a good while and was the first common-sense atom ever designed.

Here we are. We are inside a large ball made of positive electricity. Around the center of the ball we see a number of smaller bodies, which we readily recognize as electrons and which, of course, are masses of negative electricity. There is nothing here except just electricity. Thomson had the idea that all matter was nothing but that. His electrons, being all negative, would repel each other but for the fact that the shell of positive electricity held them in their places. We can easily see that this must be so where there is only one negative particle, and when it is located at the exact center of the sphere. But when there are a number of such particles the thing becomes more complicated, very complicated, in fact, and the inventor of this style of atom had to go through some difficult mathematical calculations to determine how many of these particles there could be and how

they would have to be distributed in order to be in equilibrium.

When there is only one negative particle at the exact center of the ball it is being attracted with equal strength from all sides and therefore remains at rest. This is no longer so as soon as there are more than one. However, they may be placed in such a way that their mutual repulsion is counteracted by the attraction of the ball. Let us take, for example, six electrons and place them in the form of a regular hexagon around the center of the ball. They repel each other, and this repulsion would cause them to get further and further away from each other and make a larger and larger hexagon, until the conformation bursts through the shell of the sphere—but for the fact that the central attraction prevents it. As they go further away from each other they also go further from the center of the ball. Going further from each other reduces the strength of the repelling force, while at the same time it increases the strength of the central attraction.

I can hear someone raise objections to the latter part of this statement. Going away from the center should *weaken* the attraction and not strengthen it. We all know that the attraction of the earth, the force of gravitation, becomes less when we go further away from the center of the earth. We have learned long ago that this attraction is in inverse proportion to the square of the distance from the center of the earth. An object which would weigh a pound at the surface, which is about 4,000 miles from the center, would weigh only a quarter of a pound 4,000 miles away from the surface. It would seem that the same thing should hold good for our electrons in the ball, for Thomson took for granted that this law of the inverted squares is applicable to his electrons, as well as to objects on the earth.

The reason why the law does not apply to our six electrons is that they are *in* the ball and not *on* it. This difference in position makes a world of difference in the behavior of an object. Let us first see what an object does when we let it fall from a point close to the surface of the earth, then when we drop it from a point far above the surface, say 4,000 miles, and finally when we let it fall in a hole which we have bored clear through the earth.

When we drop our pebble from some point at or near the surface, it begins its travel without any speed at all; but at the end of one second it has attained a speed of 32 feet per second. We express this by saying that the force of gravitation gives the pebble an acceleration of 32 feet per second per second. The last part of the previous sentence looks like a typographical error, but it is not. What it means is that gravitation has given the pebble a higher speed; that this increase of speed is 32 feet per second; in other words, that the rate of speed per second is increased that amount and that this has been accomplished in one second. A railroad train might also increase its speed 32 feet per second. It might have a speed at one time of 6 feet per second and at another time 38 feet per second, but it may have taken the locomotive three minutes to do this. In that case we would say that the locomotive gives the train an acceleration of 32 feet per second per three minutes.

Well, then, our pebble drops, starting with no speed at all, and acquiring a speed of 32 feet per second at the end of its first second of travel. It has traveled through a distance of 16 feet, this being the average of its rate of speed. At the end of the next second it has a speed of 64 feet per second, and it has traveled 48 feet in this second period; again the average between its initial and end speeds. The total distance traveled

in the two seconds is 64 feet, which is four times sixteen. At the end of three seconds it would have traveled 144 feet, which is nine times sixteen. In general, its total travel can be found by multiplying the square of the number of seconds by sixteen, which is half the acceleration of gravity.

Someone with a fine sense of accuracy might say that the acceleration does not remain the same all the time because, as the pebble falls, it gets nearer to the center of the earth and therefore the gravitational effect becomes stronger. This is so, but the amount which we have let the pebble fall was so little in proportion to the total distance from the center of attraction that we have taken the liberty to neglect the effect. Whether the distance is 4,000 miles or 4,000 miles plus 144 feet makes too little difference to worry about.

However, when we take our pebble to a height of 4,000 miles and let it drop from there, we can no longer say that the acceleration of gravity is 32 feet per second. In fact, it would be only 8 feet, for we are now twice as far from the center of the earth as we were before and therefore the force of gravitation is only one-fourth as much. Remember, the force of attraction is in inverse proportion to the square of the distance. However, the force—and therefore the acceleration—increases as the pebble comes nearer to the earth.

There is a point, somewhere between us and the moon, where our pebble would be attracted by the two bodies to the same extent. It would be floating until someone gave it a push one way or the other. This point is located about 216,000 miles from the earth, or 220,000 miles from its center. This is 55 times as far as an object would be at the surface. The force of gravitation is therefore 3,025 times smaller and the

acceleration of gravity is therefore the 3,025th part of 32 feet, or about one-eighth of an inch. If we should have dropped our pebble from there it would have traveled one-sixteenth of an inch the first second, and it would have taken it about fourteen seconds to travel a foot, and more than sixteen minutes for the first mile. This should be taken into consideration by explorers who intend to visit the moon and who figure on enough power to shoot them to the neutral point, depending on the attraction of the moon for the rest of the trip and on the attraction of the earth for the return journey.

However slow our pebble may be moving, it approaches the earth gradually, and the acceleration becomes greater as time goes on. The increase is slow at first, but more and more rapid as the surface of the earth is reached. At the far point the speed was very little, the acceleration was also small, and the rate of increase of this acceleration was insignificant. When near the surface, the speed was great, the acceleration was also great, and the rate of increase of this acceleration was considerable.

Now let us see what happens when we drop our pebble in the hole which we have bored through the earth. Of course, it starts under the same favorable circumstances as if we had dropped it from some point above and close to the surface. Its acceleration is 32 feet per second. As it goes further and further down we notice that its speed increases. At first the increase is very large. There is a big difference between the amounts traveled in two consecutive seconds, but as the pebble approaches the center of the earth we notice that, though the speed is still increasing, the increase is very small. This seems to be at variance with what we might have expected. At a first glance it would seem that the attraction at a distance of one

foot from the center should be four times as great as at a distance of two feet. However, when we consider things a little more carefully, we shall see that they are just as they should be—something which seems to be a habit with nature.

When our pebble is at the exact center of the earth there is an equal amount of material on every side and the attraction in any direction is counteracted by a similar attraction in the opposite direction. When the pebble is some distance away from the exact center, say a little nearer to us than to the other side, this equilibrium of the forces acting on it no longer exists, for there is more material of the earth on one than on the other side of the pebble. However, the attraction is quite small and remains so as long as the pebble is somewhere near the center of the earth. As it goes further away from that center the attraction increases, because there is then much more material on one side than on the other. We see that the attraction is greatest when the object is at the surface of the earth and that it becomes less when it approaches the center. It has been found that this attraction is proportional to the distance from the center when the object is in the earth, and in inverted proportion to the square of the distance from the center when it is outside. This condition helped J. J. Thomson to construct his atom. He could not have done so if conditions inside the ball were the same as outside.

The movement of our pebble is this: As it starts at the surface of the earth it has no speed at all but the greatest acceleration; as it approaches the center of the earth its speed increases but its acceleration becomes less and less; and when it reaches the center it has its maximum speed while its acceleration is zero. From there on the exact opposite takes place, until it reaches the opposite side of the earth when

its speed is once more zero. In a few words, it acts like a pendulum.

Eddington, in his book "The Nature of the Physical World," is not satisfied with dropping a pebble through the hole in the earth. He drops an elevator cage with himself in it. Of course, he does not notice anything because the floor of the cage is always solidly under his feet. He and the cage are going at the same speed. But Mr. Eddington has an apple in his hand. I believe it is the same apple that hit Newton on the head. The traveler in the cage holds the apple in his hand at the end of his outstretched arm. He releases the apple at the precise moment that the cage starts its downward journey. Apple, man, and cage are falling together, and at the same rate. So far as the man is concerned, he does not see the apple fall, and it seems to be at the same point where it was when he opened his hand to let it drop. However, he sees something else. As the cage goes down, the apple begins to move sidewise. It comes toward him, and at the moment that he passes the center of the earth, the apple is opposite the center of his body. From that moment on it goes away from him, and as the cage reaches the opposite side of the earth, the apple is again where it was when he started the downward journey. What gave the apple its sidewise movement? Why, nothing. As a matter of fact, the apple did not move sidewise at all. It went straight down toward the center of the earth, and as the man did the same thing, apple and man had to come to the same point when that center was reached. There seemed to be a mysterious force when there was nothing at all. This shows again how necessary it is to see with the brain as well as with the eye.

Let us see what would have happened to the electrons which we have placed in the ball, if the inside and outside conditions were the same. We are suppos-

ing that the mutual repulsion of the electrons is counteracted by the attraction of the ball and that there is a condition of equilibrium. If something happens which causes one of the electrons to move, say, the attraction of a body passing the atom, this equilibrium is disturbed and the central attraction is no longer sufficient to hold the electrons in their places. They are free to take new positions. They may have gone twice as far from the center as they were before. Their distance from each other is twice as great, and therefore their mutual repulsion is only one-fourth of what it used to be; but, as they are now also twice as far from the center, the central attraction is also reduced to one-fourth of the original amount, and so there is just as perfect an equilibrium as before. This means that the electrons can have any position and that the atom is indefinite, which, of course, does not agree with our experience which shows that the atom is a very definite thing with very definite properties.

Let us also see what would happen if the ball of electricity acted just as the earth does, that is, that the attractive force toward an object inside the ball is proportional to its distance from the center. The electrons, however, are independent bodies and their repulsion follows the law of the inverted squares. If, under those conditions, the electrons should try to get further away from each other, their mutual repulsion would become weaker, while the attraction of the ball itself would become stronger and so the electrons would be pulled back to their old places. If they should try to get nearer to the center, their repelling force would increase while the attracting force of the ball would diminish and this again would tend to restore the original condition. In other words, the equilibrium, as it exists, is a stable one.

J. J. Thomson imagined that the electrons were placed in a number of concentric rings and he figured the number of electrons which could be in each of these rings under conditions of stable equilibrium. Apparently he thought the problem hard enough when he placed all electrons in one plane, though it would have been more natural, but not so easy, to place them in a three dimensional configuration. This style of atom explained many things, but many other things would not let themselves be explained, and it is now as much out-moded as the crinoline.

We will now visit a more modern atom. Presently we are safely inside. It does not matter how we got there; what does matter is that we have arrived. This atom is an entire world, a universe such as we know. Around us—but far, far away—we see stars, slowly revolving around us as center. They appear as the planets, our own earth included, would appear if we were sitting on the sun. But there is this difference: whereas each planet of the solar system has its own orbit, the planets we see here are grouped so that a number of them travel in one path and another group in another path. What is particularly confusing is that once in a while a planet seems suddenly to disappear from its own orbit and almost simultaneously to reappear in another path, the path of some of the other planets. However, things go so swiftly that we hardly dare trust the evidence of our eyes. We shall have to study this world carefully if we wish to know just what is going on.

One of the first things we do when we observe something new, or get a new idea, or surmise, or theory, is to give it a name. The body we are sitting on and which is the sun, so to say, of this new solar system, has been given the name of *proton.* The planets we readily recognize as our old friends the electrons, and so our

atomic universe is made up of protons and electrons. Studying our new world with the kind of telescope used in intra-atomic astronomy, we come to the conclusion that there are some very important differences between this universe and the one we are acquainted with. For one thing, as we mentioned before, the planets are in groups, each group having its own orbit. Another thing, also mentioned before, these planets seem to have a habit of jumping out of their path once in a while. Then there is this striking fact, that the planets are much larger than the sun, which is the exact opposite of what we have learned about our own universe. Still another thing, and perhaps the most striking of all, is the fact that the sun, the body we are sitting on, is not a single body, but seems to consist of a group of bodies, all alike, and of another group, also alike among themselves, but different from the first group. We recognize this second group as being electrons.

Here I have to make another one of my confessions of guilt. When I said that the thing we are sitting on is a proton, I did not tell the exact truth. As a matter of fact, it is a group of protons and electrons, and the real proton is the thing I had to leave without a name because I had used that name in the previous paragraph for the entire cluster. My only excuse is that we did not see the entire truth at once and had to modify our names according to whatever new knowledge we obtained. It often goes this way in science.

Since we made a careful survey of our universe, we found that it consists of a central body, which is composed of a number of protons and some electrons, all surrounded by a number of electrons which circle around it like planets around the sun. A careful counting brings out the fact that there are twice as many protons as electrons in the central body and that

there are as many electrons circling around as there are in the central group. Of course, as is usually the case, more and more careful observation brings out some new facts which, at first, seem to be at war with our founded ideas. This often happens in science, and at first it seems annoying that we must revise our pet theories, but almost always these seeming inconsistencies bring new problems to our notice, the solution of which gives us a more complete insight into the laws of nature. A number of heretofore isolated phenomena become connected; but, alas, a new lot of problems, the existence of which was not even suspected, is put before us.

As all good astronomers do, we begin with measuring the weights and distances apart of the sun and the planets, and immediately we find some surprising things. Each of the protons of which our central sun or nucleus is built up is very heavy as compared to one of the planets; and, as there are several of these in the solar system we are visiting, the total weight of the nucleus is very great. Careful measurement shows that each of these protons is 1,845 times as heavy as one of the planets, the electrons.

Measuring the distances the planets are apart also brings a very interesting fact to our attention. Of course, we cannot express these distances in miles and still less in light years. As a matter of fact, I do not know any measure of length small enough to express these distances without using a confusing number of ciphers and so I'll cut the knot by calling the distance from the nearest planet to the sun just *one*. One of something. The remarkable fact is that, if we call this distance *one*, then the distances from the other rings of planets to the sun are four, or nine, or sixteen. The successive distances can be expressed by the squares of the numbers one, two, three, etc.

This peculiar fact corresponds very closely to what we find in our solar system, where the planets are placed in a similar manner. Not absolutely so, but near enough to make us wonder.

Still another thing which seems surprising is that the heavy protons are much smaller than the light electrons, and still another equally surprising thing is that the smallest distance between one of the electrons and the nucleus is enormously large as compared to its size and, therefore, still larger as compared to a proton. Someone suggested that if the whole atom were a cathedral, then the electrons would be motes of dust floating in it, but this is somewhat exaggerated.

While I am sitting there on that nucleus and observing the planets and their movements, I cannot help wondering what this solar system must look like to someone outside the system, and this is what I see in my imagination:

I think myself somewhere outside my atom, and place myself so that my eye is in the plane in which one of the planets rotates. Of course, I no longer see the circle (or is it an ellipse?) in which the planet moves. To me it appears as if the thing oscillates in a straight line. Its speed is quite great when it passes the center of this line, and the speed diminishes as it approaches the ends. It has a harmonic motion, the same motion I observe in a swinging pendulum. In other words, it vibrates, and it seems to make as many vibrations per second as the number of turns it makes around the nucleus in that time. There are several planets, some nearer to, some further away from, the nucleus, and the further away they are the fewer revolutions per second they make, and so I must see a number of different vibrations at the same time. Again this is very much the same as what an observer outside our solar system would see when looking at the planets.

As you know, our planets are all nearly in the same plane. They are not distributed over the surface of balls such as the various cities are distributed on the earth. It is more as if all these cities were located on the same meridian, except, of course, that they are not located on one ball but on a number of concentric balls. Our planets are not exactly in the same plane, but nearly so; near enough to make an outsider see just what we saw in the atom. To him also it seems that the planets are vibrating past the sun. Our earth, for instance, makes one vibration a year.

There is something I cannot clearly see. Are all the planets in my atom in the same plane? I am not even sure that all the planets which have the same distance from the nucleus are in the same plane. However, this would not make much difference in what an outsider would see. He would see certain planets vibrate back and forth when he places himself in one position, and certain others when he shifts his viewpoint.

CHAPTER XXI

Going Visiting

MY visit to the one kind of atom has been so interesting that I cannot resist the temptation to visit others. There may be other things to learn. Just looking on from the outside, I have already noticed that there is a great deal of difference between the different atoms. Some are quite simple and others very complicated. I'll begin with the simple ones, and none is simpler than the atom of hydrogen. This time I'll do what any good scientist would do. I shall not be satisfied with the observation of just one atom, but I'll visit quite a number; for, though they are all atoms of the same substance, I have no assurance that they may not differ, one from the other, in some respect.

Here we are inside an atom of hydrogen. This atom is certainly simply constructed. We are sitting again on the nucleus, and this time there is nothing to this nucleus but one single proton. We notice only one planet, an electron. Careful measurement of the distance from this planet to the nucleus proves that it is as near to the nucleus as the nearest planet was in the other atom we visited some time ago. This distance we called *one*. There seems to be very little else to be seen here and so we move to another atom, also of hydrogen. At a first glance there seems to be no difference at all between the two atoms of hydrogen, but when we measure the distance from nucleus to planet, we notice that it is not *one*, but *four*. The period of rotation or, if you want to call it so, the period of vibration has changed correspondingly. In still another

atom which we visit we notice that the distance is nine, in still another sixteen; in short, we find our planet in precisely the same orbits in which we found the planets in the first and complicated atom we visited. In that atom there were so many planets that there were some in the first orbit, some in the second, etc. In our atom of hydrogen there is only one electron, all told, and, of course, it can be in one orbit only.

At just about the moment when we begin to think that visiting the hydrogen atoms is a little monotonous and that there is a complete lack of excitement, something happens which makes things interesting once more. We are in an atom where the distance between planet and sun is nine, and while we are following the planet in its course we find it, not in orbit nine, but in four, and yet we did not see it jump from one orbit to another. However, we remember that at one moment there was a flash. It was at nine before the flash but afterward we see it in orbit four. This encourages us to visit more atoms and once in a while we are rewarded with a repetition of this jumping act by the electron. Only it does not always jump from nine to four. In fact, there seems to be no regularity as to where or when a planet will jump. But this much seems to be sure, that when there is any jumping at all, it is from one orbit to another, be it sometimes from a higher to a lower, and at other times from a lower to a higher. It never takes a half-way position, and it seems to take no time at all to change from one orbit to another. Furthermore, every time there is such a change of position there is a flash.

This flash interests us. We should know more about it than just the bare knowledge that there is a flash of light. We must analyze and find out what kind of light it is and what causes it. Fortunately we have an instrument for such research: the spectroscope. Of

course, we brought one with us on our visiting tour among the atoms. What we find when we apply the instrument is very interesting. In the first place we find that all the lines we get when observing the flashes are also found in the spectrum of hydrogen and, of course, this does not surprise us, for we are in the hydrogen atom itself. But we do not get all the lines of the hydrogen spectrum.

The ordinary hydrogen spectrum has a number of lines, or, saying it more correctly, a number of groups of lines. Not all of these groups can be seen by the human eye, but the camera shows clearly that there is more than one group. In each of these groups there are three prominent lines, the others being weaker and not always visible, even to the camera. We would more or less expect to find the same spectrum when we are analyzing the light of the flashes we have noticed, but we find that in each of the groups there is only one line. We notice something else besides. When the planet jumps from orbit four to orbit one we get a certain line. From now on we do not have to be so careful in our observations, for we know precisely what kind of jump the planet has made by noticing what line appears in the spectroscope.

When Fraunhofer first noticed the different lines which are characteristic of the different elements, he indicated some of the more prominent ones by letters and the three main lines of the hydrogen spectrum were labeled *C*, *F* and *G*. Sometimes there are also other and fainter ones. Whether these are there or not depends on how the spectrum was obtained; in other words, on what means were employed to make the hydrogen hot enough to produce a spectrum. There are more lines when a hot spark is used than when the spectrum is obtained from a diluted gas through which an electric current flows. All the lines mentioned

just now are in one group. Other groups show the same sequence of lines. What is interesting us at the moment is that we see only one line in each group.

Here I have been speaking of groups of lines without ever explaining what I meant. If we provide our spectroscope with the necessary devices to enable us to observe infra-red lines (the lines below the visual lines—in other words, the lines caused by heat instead of light) and also those above the visual rays (the ultra-violet rays), we shall find that there are some lines in each of these regions, and if we had made the necessary provisions to observe X-rays as well, we would have had some lines in that region also. All this is true when I direct the spectroscope at a large number of atoms at once, and in practice this is the only way we can use the instruments at all, for nobody has ever succeeded in isolating a single atom of anything. However, our imagination is not limited by practical considerations, and so we can imagine that we are looking at one atom only. What we see then is only one single line, which may be in the infra-red region or in the visible rays, or perhaps in the ultra-violet area, or even among the X-rays. Wherever the line may be, there is only one, but it jumps occasionally from one position to another, because the planet has jumped from one orbit to another.

When we observe a large group of atoms at the same time we see all the different possible jumps at once, for in one atom there may be a jump from orbit two to orbit three, in another from four to nine, in still another from five to three, etc. The very smallest amount of hydrogen which we can use for our experiment contains so many millions of atoms that we shall see many thousands of every possible kind of jump simultaneously. When I say "every possible kind of

jump" I mean every jump possible under the circumstances, for it makes quite some difference as to whether we have excited the hydrogen by a current of electricity in a Geissler tube or by an arc or by a spark.

Let us take a single atom of hydrogen and see what happens when the planet jumps from one orbit to another.

Things happen in an atom with such terrific speed that it is rather difficult to make correct observations, and we shall do well to reenforce ourselves with some facts similar to the ones we hope to observe before we look at the atom. As we are dealing here with a sun and planets on a small scale we might look at our solar system first and then see how far the behavior of the parts of the atom corresponds to that of the parts of our universe.

There is one universal force which controls the movements of planets and sun and stars, and of objects on this earth as well. It is the force of gravitation. The force which made Newton's apple fall also regulates the movement of the stars. This gravitational force is merely an attraction between two objects. Two pieces of lead, or iron, or stone, or meat attract each other, and it is not necessary that the two pieces should be of the same material. A piece of lead and another one of stone attract each other just as well as two pieces of stone or two of lead.

How strongly they attract each other depends on two things: their masses and their distance apart. When you see a stone come hurtling down from the top of a high building and kill a man, you probably conclude that the force of gravitation is a terrible one; but when, on the other hand, you place two chunks of lead close together and notice no perceptible movement of the one toward the other, you are inclined to

think that the force is either very small, or else is absent in the materials of your experiment, and only existing in the earth on which we live.

As a matter of fact, the force of gravitation is an extremely feeble one and can only be observed when the masses are very large or the distances very small. Some refined experiments have been made which show clearly that gravitation is not confined to the attraction of the earth to objects on or near it.

The force of attraction between two objects is proportional to the product of their masses and inversely proportional to the square of their distance. Two objects weighing eight and six pounds, respectively, attract each other with the same force as two other objects of three and sixteen pounds, because in both cases the product is forty-eight. Of course, this is only true if the distance between them is the same in both cases. If we had made this distance twice as great in one of the two instances the attraction would have been only one-fourth; if the distance had been tripled the attraction would have been only one-ninth. This law is called the *law of inverse squares* and seems to hold good anywhere in the universe.

Electrically charged bodies also attract each other if they are charged oppositely, but this force of attraction is enormously more powerful than that of gravity. A piece of sealing wax which has been rubbed will pick up pieces of paper quite some distance away, while two hundred-pound chunks of lead placed close together require refined methods of observation to discover that there is any attraction at all.

The swing of a pendulum is caused by the gravitational force of the earth. If we take our pendulum to the north pole we shall see it swing faster, because the force of gravitation is greater there, and if we take it to the equator we shall see it swing slower. The near-

ness of a mountain affects the rate of swing also, for the mass of the mountain is enough to cause appreciable additional attraction. Swinging the pendulum between two heavy masses of lead has the same effect as the nearness of the mountain, and as we know how great these masses are and their distance apart and from the pendulum, we can compare the force of these masses of lead with the force of the earth by carefully observing to what extent the duration of swing is affected. Such experiments have been carried out with great accuracy and have been the means of calculating the weight of this earth.

The reason why we are aware of the force of gravity is that we are always dealing with very large masses or, at least, with one large mass, the earth. The fact that the stone which fell from the roof was pulled down with enough force to kill a man was because the product of the masses of the stone and the earth was very large. Anything on this earth is attracted with perceptible force because one factor of the product is the mass of the earth.

The distance of the falling stone to the center of the earth is, roughly, 4,000 miles, because the attracting force of the earth acts as if the entire mass were concentrated in its center. This distance is very large and, according to the law of inverse squares, the effect of the attraction is greatly reduced. At a first glance it would appear as if the attraction would be less if the earth were larger and, consequently, the distance of an object on its surface greater. It is true that, if the earth were twice as large in diameter, the distance would be twice as great and the attractive force only one-fourth of what it is now; but on the other hand the mass would have increased in ratio of the cube of the diameter—in this case eight times—so that, after all, the attractive force would be divided

by four, but also multiplied by eight, and the final result would be that the attractive force is doubled.

Electrical attraction also follows the law of inverse squares. We can therefore expect the same behavior of bodies which move under the influence of electrical forces as when they are moved by gravitational attraction. The force exerted by an electrical charge is enormously large as compared to the body which carries it. The electron carries a charge of negative electricity; it is, perhaps, nothing but a disembodied bit of electricity. The proton carries a corresponding charge of positive electricity, and therefore it attracts the electron. The question is, why doesn't the electron fall back on the proton for a lasting happy reunion? To find the answer we will have to consult the stars and falling stones.

A weight of ten pounds, fifty feet above the ground, is said to have a potential energy of five-hundred foot-pounds in regard to the level of the ground. This means that if I should attach it to a rope, put the rope over a pulley, and place another ten-pound weight at the other end of the rope, the first weight would be able to raise the other if I should start it downward with a touch of my finger. In reality there would be some losses, such as are caused by the friction in the pulley arrangement, the resistance of the rope against bending, and the resistance of the air. If I should build a platform twenty-five feet above the ground, the potential energy of my ten-pound weight in regard to that level would be only half as much as before.

If I should drop the weight from the height of fifty feet, it would reach the ground after a time, and then it would have no potential energy at all in regard to its new level. However, it now would have a new kind of energy, the energy of motion, or, as it is called, kinetic energy. This energy, though of a different kind,

is the same in amount as the potential energy it had when it was on the high level. This can easily be proved. We arrange a seesaw and place a ten-pound weight on one end. We let our weight fall from a height of fifty feet and aim it so that it strikes the other arm of the seesaw. If there are no losses due to resistance of the air and friction in the pivot of the seesaw and if we did not have to give momentum to the seesaw itself, the lower weight would be tossed up to the same height as the height from which our first weight had fallen. Even as it is, the tossed-up weight reaches somewhere near the fifty-foot level. If I had erected a platform at the twenty-five-foot level, the weight would have lost half its potential energy when it reached the platform, but it would have acquired so much kinetic energy that its total energy would have been just as much as it was originally. The sum of the potential and kinetic energies of a body in relation to a certain level remains constant. This is something which we must remember when we study the behavior of an electron when it drops from one orbit to another.

A projectile shot out of a gun travels a certain distance before it reaches the ground. If we should aim the gun in a horizontal direction, and if there were no gravitation, the projectile would get farther and farther away from the earth because the earth is round and the projectile travels in a straight line; that is, if we neglect such disturbing factors as the resistance of the air. Even as it is, gravitation and all, the projectile travels farther than if the earth were flat. The greater velocity we give to the projectile, the farther it travels before it comes down to earth. If we should give it an initial velocity of five miles per second, it would never reach the earth, but would go on forever, circling around just as the moon does,

always neglecting the resistance of the air. If we give a greater velocity than five miles per second, it will describe an ellipse, losing speed from the start to half way around, and then, when it is on its return journey, gathering speed again until it has its initial speed by the time it has come back to its starting point. If we should give it a velocity of about seven miles per second, it would go off into space, never to return.

All these things are the same whether the force is that of gravitation or of electrical attraction, and so we can study the behavior of an electron under the attraction of a proton by observing the laws which control the movements of the stars. However, we shall find one point of difference.

In order to see more clearly just what happens in our atom of hydrogen we shall stay outside the atom this time where we shall have the chance to observe several atoms simultaneously and compare what goes on in them. We notice some atoms where the planet is in orbit five, some where it is in four, others where it is in three, still others where it is in two and even a few where it is in one. If conditions are proper we shall see some where the planet revolves in larger orbits, but just now orbit five seems to be the limit. We can easily see the reason why this is so. The size of the atom is the size of its outermost orbit, so that we cannot properly speak of the size of atoms in general. Some are large and others are small. When there are many atoms in a given space they crowd each other and there is no possibility of large atoms being undisturbed. However, such large atoms may be found if the gas is very much attenuated.

Occasionally we see a planet jump from one orbit to another. Sometimes one goes from a higher to a lower orbit, and sometimes the reverse. Of course,

the planet which is in orbit one cannot go to a lower one for then it would cease to be a planet, because it would have arrived on the proton, the sun. The peculiar thing about it all is that no planet ever seems to stop at a half-way station. They confine themselves strictly to the proper orbits. Having observed all this we will now take some time to compare these phenomena with what we have seen about ten-pound weights here on earth, and the stars in the sky.

Take, for example, an electron in orbit five. It is subject to the attraction of the proton, and, if given a chance, it will fall toward it just as our ten-pound weight will fall toward the earth if there is nothing to hold it. In other words, it has potential energy in relation to the level of the proton. If it falls toward a lower level it loses some of that energy and, as we have seen, this is no real loss but merely a conversion of potential into kinetic energy. The electron has also a certain amount of kinetic energy, because it is in motion around the proton. The question now before us is this: Is the kinetic energy of the electron more when it travels in a high orbit than in a low one or is it less? The laws which control the movements of the planets must be applied here to get the answer. One of the well-known laws of Keppler says that the line which connects the sun with a planet moves over equal areas in equal times. To illustrate: the earth describes an ellipse around the sun. In one day it describes the three hundred and sixty-fifth part of this ellipse. However, this does not mean that it completes $1/365$ part of the elliptical path but that the two lines which join the sun to the earth at the beginning and the end of the day and the path described by the earth itself form a triangle of which the area is the $1/365$ part of the entire ellipse. When the earth is

at the far end of the ellipse, the line which connects it to the sun (called a radio vector) is longer than when it is at any other point of its course. The triangle described in one day, however, has no greater area and, therefore, the third side—that is, the path described in that day—must be shorter. The speed of the earth is a minimum when it is far from the sun and a maximum at the opposite end.

It is a little difficult, though not at all impossible, to calculate the amount of kinetic energy of these various planets. The only thing we need to know, besides the speed, is the masses of each of these planets, and not only is this possible, but as a matter of fact the masses have been calculated with a high degree of accuracy. Conditions in our atoms are much simpler, for there all the planets have the same mass. We need only consider the speed if we wish to compare the amounts of kinetic energy of the electron in the various orbits.

Let us compare the amounts of kinetic energy of two electrons in orbit one and another in orbit two. The distances from the proton are one and four respectively. Another of Keppler's laws says that the squares of the periodic times of the planets are proportional to the cubes of their largest distances from the sun. These distances in our atom are one and four. Their cubes are one and sixty-four, and the square roots of these cubes are one and eight. It takes an electron in orbit two eight times as long to complete a revolution as one in orbit one. On the other hand, this slow electron has traveled over a path four times as long as the path of the other electron, so that its speed is just half as much and, therefore, its kinetic energy is one-fourth of that of the other electron, for kinetic energy is proportional to the square of the speed.

The farther an electron is away from the center—the proton—the smaller its kinetic energy. On the other hand, its potential energy is greater, because it is farther away from the center, just as the potential energy of our ten-pound weight was more when it was at a height of fifty feet than when it was at twenty-five feet. Simple mathematics and a little knowledge of the laws of mechanics are sufficient to show that the sum of these two kinds of energy is greater for the electron in the larger orbit than for the one in the smaller orbit. This fact is of great importance, for it explains many things.

When an electron jumps from orbit two to orbit one, or in general from a higher to a lower one, it gains kinetic energy, it loses potential energy, and it loses more than it gains. What becomes of this lost energy? The law of conservation of energy tells us that this lost energy must be found again somewhere in some form or other. Well, this so-called lost energy is converted into radiation, and it is this radiation which we observe when we look at an atom through the spectroscope. Whenever we see lines, we really see changes of orbit which take place in this or that atom. As in even the smallest possible amount of the most perfectly attenuated gas there are still many millions and even billions of atoms, we must necessarily see all the possible changes that can take place, and so we do not see a single line but all the lines which all these changes would produce.

As I said, there is not much chance that electrons will be found beyond the fifth orbit, on account of the crowded condition in which the atoms would then be, and as they cannot be lower than in the first orbit it would seem that the electrons cannot make many different kinds of jumps. And this is really true. An electron in the fifth orbit can take

only four new positions—namely, to the fourth, the third, the second and the first orbit. Similarly, one in the fourth orbit can take only three new lower positions; one in the third orbit can take only two, and in the second orbit only one. It would seem, therefore, that after a time all the electrons must arrive in the first orbit and that then all radiation must cease. This would be so if no electron ever jumped from a lower to a higher orbit. This the electron cannot do unless it is helped by some outside assistance, for going to a higher level means that it gets more total energy than it had before the jump. It gets such outside help from different sources. The atom may be struck by radiation coming from somewhere, or it may be struck by some wandering electron or, perhaps, by X-rays. In this way it may receive enough additional energy to lift it from a lower to a higher level.

We saw that the total number of possible jumps is ten, but we notice many more lines in the spectrum of hydrogen. How many lines we see depends on the manner in which we obtain the spectrum. There are many more lines when the spectrum is the result of heating the gas with a spark than with an arc, but even in that case we see more lines than can be accounted for by the possible number of jumps from orbit to orbit which the single electron of the hydrogen atom can make. Radiation makes us naturally think of vibration, and vibration leads our thoughts to sound and when we think of sound we cannot help thinking of music.

When we hit a string on the piano or blow some air into an organ pipe we get a sound, the pitch of which depends on the length of the string or the column of air in the pipe. It should not make any difference whether the organ pipe is made of wood

or of metal, but we know that it does. The pitch is the same but the quality of the tone is different. The reason is that each of the notes is accompanied by a number of overtones or harmonics and that these harmonics are not the same for metal and wood. Even if they are the same, they are not present in the same proportion. As was mentioned before, these overtones bear a very simple relation to the fundamental note.

The number of vibrations per second of these overtones are simple multiples of that of the basic note. If, for instance, we strike middle *C* we hear also the *C* one octave higher (twice the number of vibrations), the *G* above this *C* (three times the number), the following *C*, etc. If the number of vibrations of the base note is indicated by the figure 1, then the number of vibrations of the overtones can be indicated by the numbers 1, 2, 3, 4, 5, 6, 7, etc. The reason why these overtones are called harmonics is that they give a pleasing effect when combined with the fundamental note. I should, perhaps, modify this last statement somewhat. The overtone which is indicated by the number 7 does not produce an harmonic effect, in fact, it is rather in the nature of a discord. It is interesting to note that it is for this reason that the piano-maker places the hammers so that they strike the strings at a point one-seventh of the length, in order to kill this undesirable overtone.

It is rather natural that we should expect such harmonics in other cases of vibration. We might look for other lines in the spectrum, lines which should represent vibrations of twice, three times, four times the frequency of the fundamental vibration. The wave length and, therefore, the frequency of a line in the spectrum is known by its position and we only need to measure the correct positions of the various lines we see in order to find what their frequencies are.

This has been done for the lines of the hydrogen spectrum and it was found that these lines corresponded fairly closely to where they might have been expected to be if they had been harmonics of the base note, but not entirely so. The difference was too great to be accounted for by the assumption that the observer had made some slight error or that the instrument was not entirely correct. Furthermore, not all observers and all instruments could be charged with the same error. As is so often the case, the very fact that we did not find what we had wished and expected to find, the fact that we were up against a new and unexpected problem, set bright minds to work and led to a solution which clarified things even more than if we had found what we had thought we would find.

The Swiss, Balmer, and especially the Danish physicist, Bohr, formulated a theory which explains many things, and which is in complete accordance with all the facts as we know them now.

Balmer presented a formula in which he used the letter n. Substituting for this letter the integer numbers 3, 4, 5, etc. (but never less than 3), one was supposed to get the various numbers of vibrations corresponding to the various lines in the spectrum. This came very near reality, but not entirely so. Bohr presented a modification of this formula which meets all requirements.

Much to my regret and, probably, to the disgust of some readers, there is no good way of telling about Bohr's formula except by writing it down. This formula is:

$$B\left(\frac{1}{n_1^2} - \frac{1}{n_2^2}\right)$$

The n_1 and the n_2 must be integers and any integer substituted for either of the two n's gives a proportion-

ate position for some line of the spectrum. In order to know the exact position we must also know the value of B. To illustrate: let us suppose that B is 216,000 and let us then compute by means of this formula what the proportionate values of some of the lines of the spectrum would be. When I say "value of a line" I mean the frequency of that part of the light represented by that line or, in other words, the number of waves per second.

We will first substitute for n_1 the value 1 and then make n_2 successively 2, 3, 4, etc. If n_1 is 1 then the square of n_1^2 is also 1 and the value of the first fraction is likewise 1. If now we substitute successively 2, 3, 4, etc. for n_2 we shall find the following values for the squares of $n_2^2 \div 4 - 9 - 16$, etc. and the value of the fraction $1/n_2^2$ becomes $\frac{1}{4} - \frac{1}{9} - \frac{1}{16}$, etc. The expression between brackets becomes then $1 - \frac{1}{4} = \frac{3}{4}$, or $1 - \frac{1}{9} = \frac{8}{9}$, or $1 - \frac{1}{16} = \frac{15}{16}$, etc. Multiplying these values with B (for which we have assumed the value 216,000) we get the following proportionate frequencies: 162,000 or 192,000 or 202,500, etc. These figures give the values for the different lines of one series. We shall get another series if we use the value 2 for n_1. Anyone inclined to do so can figure out for himself what the value of the expression between the brackets will be if, again, he substitutes the values 3, 4, etc. for n_2. He will find 30,000 – 40,500 – 51,840, etc. if he makes n_1 equal to 2, and 10,500 – 15,360, etc. if he makes n_1 equal to 3.

It should be noted here that one can use any integer for n_1 but the smallest value one can use for n_2 must be one more than the value used for n_1, otherwise the expression becomes zero or even negative, and this would have no meaning.

Every time we take a new value for n_1 we get a new series and every time we take a new value for

n_2 we get a new line in some series. This idea, as propounded by Bohr, is a very pretty one, but the question now is whether it checks with reality. The positions of many lines of the hydrogen spectrum were carefully measured and the corresponding wave lengths and frequencies computed, and it was found that the theory corresponded absolutely with the facts as found. Not only that, but the theory pointed out that in some cases there must be lines in the spectrum which, so far, had not been observed, but which later were found when the observer knew what to look for. Bohr's idea deserves, therefore, to be called a theory.

We must now give up the idea that there are harmonics accompanying a vibration set up when an electron drops from one orbit to another. This is no loss to us, for in its place we have acquired a more complete and understandable theory. According to Bohr the n_1 in his formula represents the number of the orbit *to* which an electron drops, and the value substituted for n_2 represents the number of the orbit *from* which it has dropped.

Picking out some particular line in the spectrum we can find its wave length and, therefore, its frequency. We can also see in which series of lines it lies and its position in that series. In other words, we have the solution of the Bohr formula, and we also have the particular values of n_1 and n_2 and we can therefore calculate the value of B. This was done by Professor Rydberg and the result is known as the *Rydberg constant.* It is a large number and will not be given here, because it would be forgotten anyhow.

CHAPTER XXII

How Do You Know It?

IT seems to me as if I hear someone asking this question. Perhaps there is more than one asking it. How do you know that atoms are built up of protons and electrons? How do you know that the electrons, if there are any, revolve around the proton? And if that is true, how do you know that there are several possible orbits and that the electron jumps from one to another? After all, that description of sitting inside an atom and looking at an electron through a telescope is mere fancy, and just how do you know anything about a thing you cannot hope to see?

Perhaps the best way to answer these questions is to mention something else we know, but which we have not seen.

Suppose a man has been murdered and robbed. Somebody is arrested and accused of the murder. It is known that the accused had a violent hatred for the murdered man. It is also known that the accused was in the neighborhood of the place where the murder was committed. Furthermore, the bullet that killed the murdered man fits a gun which is recognized as having belonged to the accused, and some of the property of the victim is found in the accused's pockets. Suppose all of these things were ascertained, but that nobody had seen him commit the crime. Don't you think that a jury of twelve men, good and true, would find the accused man guilty, and be so sure of it that they would doom him to the electric chair?

Nevertheless, it may happen, and it has happened, that after all somebody else committed the crime. Well, the circumstantial evidence in the case of the atom is at least as strong as that against the accused man, and, what is important, science condemns nobody to the electric chair. At the worst, it places the culprit where he must stay until released. He will be set free if further evidence turns up which shows that not he, but someone else, is guilty.

We, the men of the jury, must weigh the evidence which the prosecuting officials, the scientists, have presented to us, and if we find the evidence sufficient we must give a verdict accordingly.

For many centuries philosophers were satisfied to let their imaginations roam wherever they pleased. They did not ask for assistance from carefully observed facts, but neither were they hampered by them. As a result we may read of many fearfully and wonderfully made theories of the ancients. Some of these theories were mere nonsense, but there are others which came so near the truth, as we see it now, that we must admire the men who could think so deeply and so correctly that they could develop sound theories without any other material than their own gray matter. However, though we may well admire the intellect of these men, we cannot approve of their methods, for to find a verdict without having listened to the evidence is against our ideas of fair play. Such theories, if developed in this manner at the present day, would find no adherents except among people who are willing to listen while the astrologer and the numerologist are on the air.

A few hundred years only have elapsed since the wise men of the world accepted the idea that our knowledge must be based on our observations; in other words, that we must learn to see and hear and

feel and smell and taste correctly before we can begin to think. When this idea was once accepted, it was soon found that our senses are very limited. They give us a general idea of the way things are, but do not show up the fine details. Even at their best they only show that there is some difference between two sounds or colors or tastes, but they do not tell us anything about the amount of that difference. They register the existence of a condition, but they do not measure.

Gradually the scope of our senses has been enlarged by the invention of instruments. Now we can see things which are so dim that our eyes are not affected by them. We can see things so small that we never would have suspected their existence without the microscope. We can see through things which are opaque to our eyes. We can record all these things on the photographic plate so that we shall have not just a fleeting glimpse, but a permanent record which we can read at our leisure whenever we please.

Our senses of taste and smell tell us of the chemical difference between various substances, but they are very inefficient instruments indeed compared to the spectroscope. We are able to say that one thing is somewhat heavier or lighter than some other thing, provided the difference is great enough. But compare this with the finest chemical balance which will weigh a pencil scratch. And so on, all along the line, the capacity of our senses has been multiplied enormously by the invention of instruments.

However, almost as soon as the scientist was enabled to observe more and to observe better by these instruments, it became evident to him that there was still something lacking. He found it to be of the greatest importance that he should be able to measure as well as to observe a phenomenon. And

so the next development was in the direction of measuring instruments. The foundry man considers a quarter of an inch as about the smallest unit of length with which he has to deal in his trade. The plumber goes down to a sixteenth, and the mechanic in the machine shop to a thousandth or sometimes a tenth of a thousandth of an inch. The scientist is not satisfied with the millionth and is continually trying to measure within finer and finer limits. When Millikan measured an electron he had to deal with dimensions so small that I hate to put them down on paper for fear of dismaying the reader with the string of ciphers.

Besides the magnifiers, if I may call them that, and the measuring instruments, there is still something else required to convert observations into knowledge—namely, thinking power. It seems that brain power is not an invention of modern times. Some of the keenest thinkers of whom we know lived more than two-thousand years ago. Some people go so far as to say that late centuries have never produced intellects comparable to some of the old Greeks, but this is going too far, and is probably the result of the same trend of mind which cannot conceive that anything is beautiful unless it is antique.

Just as our senses have their limitations, so have our thinking powers. Our chief limitation lies in the fact that we cannot think of more than one thing at a time. Our thinking must be consecutive, which makes it rather difficult when we are confronted with a large mass of observations and data. Not only that, but some facts and figures are so complicated, so interwoven—matted, I might almost say—that it is practically impossible to handle them without getting confused. However, here, too, an instrument has been invented which enables us to do what we

cannot do without its assistance. This instrument is mathematics.

It cannot be far from the truth to say that mathematics is as old as the human race. Perhaps the only sharply drawn dividing line between human beings and the other animals is mathematics. Whenever the scientist gets to a place where things become too much for him he calls in mathematics. This may be the reason why he cannot tell the lay world what he knows, for he does not know it himself, except in the language of mathematics, and this is a language that many people detest, some endure, and but few love.

I really should have spoken of mathematics in the plural, for there are many branches or kinds. Whenever some scientist finds that the existing mathematics is not sufficient to help him with his problem he sits down for a few hours or years and develops a new branch.

Some things can be measured directly. It is no great trick to measure the pressure of steam at a given temperature. We have instruments which will do this for us. Neither is it very difficult to measure the proportion in which some elements combine with each other, though in this case considerable care on the part of the experimenter is required. On the other hand, there are many instances in which no such direct method can be followed. It is not possible to count the number of molecules in a cubic inch of gas, nor can we apply a two-foot rule, or even a finely divided scale when we wish to know the length of a light wave. In such cases indirect methods must be followed and great ingenuity is often shown in the development of such indirect methods.

To refer back to our simile of an accused before the bar of justice, it is but seldom that the defendant is

caught redhanded; circumstantial evidence is the best we can hope for in most cases. The layman, not acquainted with these indirect methods, is apt to doubt the result of much painstaking observation and careful thinking and calculation, and to remark that it is easy for you to tell him what the distance to the sun is, because you know very well that he cannot go there and check you up.

It would seem that the field for direct observation and measurement in the sciences of physics and astronomy is almost exhausted. So many men have been busy for so many years in observing the materials and phenomena around us that new materials and phenomena must necessarily be few and far apart. Even those few which now and then are brought to light are generally the result of premeditated effort to produce them. Some scientist has been digesting part of the accumulated knowledge on some subject or other and as a result has developed a provisional theory. He then studies this theory and decides that, if he is right, there must be such a condition to be observed. From then on he goes back to experimentation. Quite often he finds what he expected to find, and feels surer than before that he is on the right track. Sometimes his experimentation gives only negative results which neither prove nor disprove his preliminary theory, and sometimes he finds that he is wrong because his experiments demonstrate the very opposite of what he had expected. Whatever the result may be, he has learned something and he is in a better position than before to find the truth at some future time.

Thomson's idea of the structure of the atom explained a great many things, but it failed to explain the fact that different elements gave different spectra and so it had to be dropped. There is another kind

of atom model, which also explains many things, but which also fails to account for the fact that each element gives out its own particular set of radiations. It too had to be dropped. In this model the electrons and protons are distributed in space, for instance at the eight corners of a cube. Neither the electrons nor the protons move and, consequently, they cannot contribute to the vibrations which we observe when we study the spectrum. However, it comes very close to explaining the reason why certain materials have various crystal forms.

The atom model we have been considering somewhat in detail previous to this one comes nearer to being entirely satisfactory than any of the others; but it, too, is still in the probationary state. It explains very nicely for the simplest atoms, such as hydrogen and helium, but it leaves us still in a haze when we try to apply it to the more complicated ones. The reason is that many electrons in many orbits make the mathematics of the case so formidable that no one has as yet succeeded in solving the problem in an entirely satisfactory manner. The circumstantial evidence is not yet complete.

And so this is the answer to the question, "How do you know it?": we don't. Not entirely. Much of the evidence is in, but not enough to give the case to the jury for a final verdict. Some of the evidence at hand is very convincing, and if it were not for some disturbing elements which I have not mentioned so far, this chapter might well be closed.

The whole question as to how an atom is constructed reminds one of the old-time jig-saw puzzle. It is worse, in fact, for we do not have the completed picture before us to guide us. We must go entirely by the way one piece fits into another. Sometimes we

find two pieces fitting nicely together, but they do not make a piece of any picture at all, and sometimes we find two pieces which would make a part of some picture but they do not happen to fit each other. In the case of the atom we have some pieces which fit and which also seem to make part of the picture, but we do not yet have all of the pieces, or, if we have, we do not yet know how they should go together.

One of the most important pieces of our puzzle is the periodic table. Take the idea of the planetary system of the atom and combine it with the idea of the periodic table and you get a pretty complete picture. It is this way:

All atoms are supposed to be made up of protons and electrons. All the protons are closely packed together in the nucleus. In addition there are in this nucleus half as many electrons as protons. If, for instance, as is the case with helium, there are four protons in the nucleus, then there are two electrons combined with them. There are also a number of electrons revolving around this nucleus. The atomic weight of an element is controlled by the protons; for, as we have seen, a proton weighs 1,845 times as much as an electron, so that we are justified in ignoring the electrons altogether as far as weight is concerned. However, the chemical behavior of the element is entirely controlled by the free electrons. If we should have two elements with the same number of electrons but with different numbers of protons, we would not be able to distinguish these elements chemically. They would be isotopes. If, on the other hand, we should have two elements with the same number of protons but with different numbers of free electrons, we would be able to distinguish them from each other by their chemical behavior, but they would have the same atomic weight. We have already made the acquaint-

ance of the isotopes, and we have also met elements with the same number of protons but different numbers of electrons, but we have not been introduced to them. We met them when we were speaking of the gradual disintegration of uranium into lead. In some cases the element would lose both protons and electrons, in other cases electrons only. In both instances a new element would appear but the atomic weight would not always be changed.

However, the atomic *number* did change, for it depends on the excess of protons over electrons in the nucleus. Take the element uranium, for instance. Its atomic weight is 238 but its atomic number is 92. This means that there are 92 more protons than electrons in the nucleus. If, in its spontaneous explosion, it shoots off an electron, its weight is not changed, but, nevertheless, it has become a new element. It also becomes a new element when it shoots off a helium ion, which is composed of four protons and two electrons. In the latter case both atomic weight and atomic number are changed.

At the present, the highest atomic number is 92, but it is possible that, sometime in the future, a new element may be found of a higher atomic number. It is not probable, but it is possible.

An element may lose some of its electrons in two different ways. The electrons may be lost from the nucleus or from the surrounding planets. In the first case it becomes an entirely new element, but in the other case it becomes merely an ion, which, to all effects, is the same element electrically charged.

Let us forget for a little while the idea that these electrons revolve around the nucleus and let us see instead how they should be distributed to account for the chemical behavior of the various elements. Heretofore we have placed them in concentric circles

or ellipses, but now we shall place them in shells surrounding the nucleus.

The simplest element of all is hydrogen. It has an atomic weight of one, which means that there is only one proton in the nucleus. Its atomic number is also one, and this means that there is one more proton in the nucleus than there are electrons. In other words, there are no electrons in the nucleus at all. There is only one planet; and, as we have seen, there is no way of accounting for the fact that this electron is not pulled into the nucleus except by assuming that it revolves around the proton like a planet around the sun. Since we have, for the present at least, discarded the idea of such a solar system, we must find some other reason why the electron does not react to the attraction of the proton.

Now, hydrogen atoms do not appear in nature as such. We see them always in pairs, as molecules. It is easy to imagine how two hydrogen atoms can group themselves so that the attraction of the protons and electrons is counteracted by the repulsion of the electrons themselves. Something like this:

$$\begin{array}{ccc} & P & \\ E & & E \\ & P & \end{array}$$

There is no element known with two or three protons—in other words, with an atomic weight of two or three. The next element is helium with an atomic weight of four and the atomic number two. It has, therefore, four protons and two electrons in the nucleus. It is possible to imagine protons and electrons so placed that they hold each other in equilibrium. There is no tendency at all to change the configuration or to combine with some other atom in order to arrive

at a state of equilibrium. We express this by saying that helium is an *inert gas.*

When we try to place a number of electrons in a single shell around the nucleus, we find that we are very much limited as to the number of electrons which can be in equilibrium. In the case of helium there were two. The next number we can use in one shell is eight. If we want more than this number we must place them in two shells. Summing it all up, we can place electrons in concentric shells in such a manner that there shall be a perfect equilibrium, but only if we put

2 in the first shell
8 in the second
8 in the third
18 in the fourth
18 in the fifth, and
32 in the sixth.

Elements which have just these numbers of electrons in the successive shells are the inert gases. They are:

helium............	2 electrons
neon..............	10 electrons (2 plus 8)
argon.............	18 electrons (2 plus 8 plus 8)
krypton...........	36 electrons (2 plus 8 plus 8 plus 18)
xenon.............	54 electrons (2 plus 8 plus 8 plus 18 plus 18)
niton.............	86 electrons (2 plus 8 plus 8 plus 18 plus 18 plus 32)

If there are more or less than the proper number of electrons in a single shell the equilibrium is not stable. It has required some nice mathematical calculations to determine the number of electrons in the various shells, but the results coincide with the observed facts. That is, all the elements which, according to these calculations, are inert, are found to have the atomic weight which these calculations predict.

CHAPTER XXIII

Too Much or Too Little

THE inert gases have just enough electrons in the various shells. All other elements have either too many or not enough. The element with the next higher atomic number after helium is lithium. It is number three in the periodic table and has an atomic weight of six. This means that there are six protons and three electrons in the nucleus. Three of the protons are neutralized by the three electrons in the nucleus, while there are three more electrons in the surrounding shell. These last three are crowded in a shell which can hold only two if there is to be a permanent equilibrium. In other words, there is one too many. The next element in the table is beryllium with the atomic number four and an atomic weight of eight. It has four electrons in the shell and these electrons satisfy the four unneutralized protons in the nucleus, but they are crowded in a space which should have only two, so that there are two too many. Next comes boron with the atomic number five and with five electrons in the shell, so that there are three too many.

The following element in the table is carbon with the atomic number six and six electrons in the shell, whereas there should be only two for permanency. Carbon has four too many. However, when we say this we are a little arbitrary, for we have been placing the electrons in the first shell whereas we might have placed them just as well in the first and the second. As we know, the second shell can take care of eight electrons and if we had placed two of the electrons of the carbon

atom in the first shell and the other four in the second, we could have said that we are lacking four electrons for a permanent equilibrium. If we try to crowd all the electrons in the first shell we have four too many, and if we try to divide them between the two shells we are four short.

The probable truth is that we shall find now the one and then again the other arrangement. However, when we go on, we next find an element, nitrogen, of which we would have to say that it has five too many if we try to crowd all the electrons in the first shell, whereas we could say that it is three short if we dispose the electrons in two shells. It is therefore more likely that the electrons are to be found in the two shells. Starting with helium we would find the following:

helium	just right
lithium	one too many
beryllium	two too many
boron	three too many
carbon	four too many or four short
nitrogen	three short
oxygen	two short
fluorine	one short
neon	just right

The first element, helium, has no valency—no hooks—at all. It does not combine with any other element. The second, lithium, is univalent—it has one hook—and it combines with other elements. Beryllium is bivalent—it has two hooks—and can combine with some other bivalent atom or with two univalent ones. Boron is trivalent and carries three electrical charges in solution. It can combine with three univalent atoms or with a bivalent and a univalent one or with another trivalent atom. We then come to carbon which, as we have noticed before, is tetravalent, and which can combine in many dif-

ferent ways with other elements or hook up with other atoms of carbon.

We have now exhausted the first horizontal row of the periodic table. In fact, we have entered the second one, for neon belongs there. Neon is the first element of the second row. The second in this row is natrium or sodium. Its atomic number is eleven and it has eleven free electrons, which find their places partly in the first and partly in the second shell. However, the combined capacity of these two shells is ten, so that here again we have one electron too many for a permanent equilibrium. Sodium is univalent. The next element, magnesium, has two electrons too many and is bivalent. The next one, aluminum, has three too many and is trivalent. Then follows silicon, which has either four too many or may be said to be four short. Phosphorous, which comes next, has five too many or is three short, and in its chemical behavior acts sometimes one way and sometimes the other. This is also true of sulphur, which may be said to require two more or to have six too many. The next element in the table is chlorine which has seven too many or is one short.

Those atoms which have too many electrons tend to combine with atoms which do not have enough. The first kind of atom is called electro-negative while the other is called electro-positive. However, when we say that an atom has too many electrons we are not very specific. We should say that it has too many if we imagine that they are placed in a certain shell; but if, on the other hand, we think that some are placed in the next shell, we can say with equal reason that it has not quite enough. In other words, it is electro-positive if we look at it one way and negative if we consider it in a somewhat different light; and, as the atom does not know how we have

been looking at it, it behaves sometimes one way and sometimes another, according to circumstances.

There are two conditions which must be met in the atom as we are imagining it now. There must be enough planet electrons to neutralize the nucleus, and there must be just the right number of them to fill the various shells we have placed around the center. Half the number of protons is already neutralized by the electrons in the nucleus itself. The other half must be satisfied with the electrons in the shells. There is only one number of electrons which we can place in any one shell and produce a permanent equilibrium, so that all other numbers leave something to be desired. It is fortunate for us that this is so, for if all atoms were in a state of perfect equilibrium there would be no compounds and we would have to be satisfied with the elements as we found them. For that matter, we would not be here to regret this state of affairs, for our bodies are compounds of atoms and very complicated ones at that.

We can imagine various ways in which this compounding takes place. We have seen how the idea of hooks was once used to give us some kind of picture of the behavior of atoms. It gave us a picture, but nothing else, for everyone realized that the atoms really had no hooks. The idea of placing the electrons in rings or shells gives us a more complete picture. Besides, it is based, not on a fanciful conception, but on reality, for we know that there are electrons and protons and it is only their relative position which is still more or less a conundrum to us.

Figure 21 illustrates one way in which we can imagine what happens when two atoms combine. Figure 21*A* shows the two atoms apart, and Fig. 21*B* shows them combined. I have chosen the atoms of sodium and chlorine. The heavy dot in the center represents the nucleus

and also the two electrons of the first shell. The dots in the circles represent the free electrons. There are 9 of these in the sodium atom and 15 in the atom of chlorine. Perfect equilibrium would require that there be 8 in the sodium and 16 in the chlorine atom.

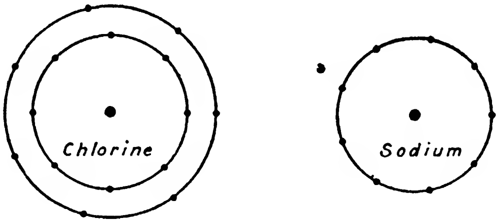


FIG. 21*A*.

The two shells are brought very close together in Fig. 21*B* and we see that the one extra electron of the sodium has found a place in the shell of the chlorine, so that now both circles have the proper number of electrons and there is neither crowding nor shortage.

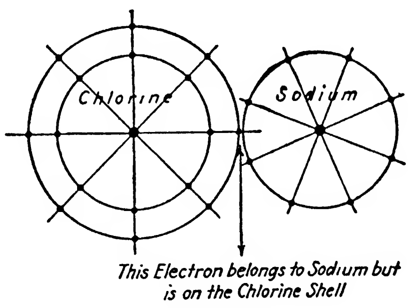


FIG. 21*B*.

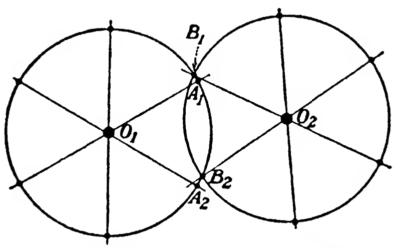
However, the nucleus of the chlorine atom can take care of only fifteen electrons in the shell, whereas the nucleus of the sodium atom now has surplus attractive power, for it can hold nine electrons whereas there are only eight in its shell. The two shells are so close

together that the sodium nucleus can still attract its ninth electron, though it is at present in the shell of the chlorine atom. We cannot say that the one atom has lost and the other has gained an electron. We should rather say that the one has loaned an electron to the other but still holds control of it. It might be compared to a partnership where one partner furnishes the money and the other the knowledge for the business. So long as the partnership endures, money and knowledge belong to both, but as soon as it is dissolved, the money is returned to the one while the other naturally keeps his knowledge. But please remember that this is a simile and, like all similes, only partly correct.

The inert gases, such as helium and argon, have atoms which are entirely complete and self-sufficient. There is no reason why they should combine with other atoms. Neither is there any reason why two or more atoms of the same gas should come together and form a molecule. Each atom is a molecule in itself. This is not the case with other atoms. We have seen why two atoms of hydrogen come together to form a molecule of that gas. It is not always so easy to see why some of the other atoms should behave this way. An atom of oxygen, for instance, lacks two electrons, and when it joins another atom of the same element this shortage does not seem to be made good, for the other atom also lacks two electrons. Our imagination must come to our assistance; we must suppose that such a thing is happening, but whether it really does happen cannot be taken for granted until experimentation or new or as yet undigested knowledge furnishes the necessary evidence.

Figure 22 shows one way in which we might explain the forming of a molecule of oxygen though both atoms have a shortage of electrons in the outer shell. Each atom

should have eight electrons whereas it has only six in that shell. These atoms are again represented by dots on the circumference of a circle. The two circles overlap each other and in this way two of the electrons of the first atom furnish the two lacking in the second one, while two of the second one furnish the two lacking in the first. In this drawing these helpful electrons are not situated on the circle which they are supposed to complete, but this is so because I have arbitrarily assumed that there must be circles. The electrons may



A_1 and A_2 belong to O_1 but are also under the influence of O_2. B_1 and B_2 belong to O_2 but are also under the influence of O_1

FIG. 22.

be placed in an entirely different way and yet the same method may be followed by nature to make molecules out of atoms. Of course all this is more or less in the nature of conjecture. However, one thing is certain: the bond between two atoms of the same element does not seem to be as strong as that between two atoms of different elements. It is only when an atom finds nothing else to attach itself to that it hunts up a similar atom and joins it.

In the early days of the science, when but a relatively few elements were known, it was noticed that many of them had atomic weights which could be expressed by integer numbers. Others had atomic weights which came so near to integer numbers that it

was assumed that some small error had crept in in some way, but that, if the proper methods were followed and the proper instruments were at hand, it would be found that these elements also would have atomic weights which could be expressed by integer numbers. By and by better methods were developed and more and more accurate instruments were invented, but the objectionable fractions remained. If various skilled experimenters had found different atomic weights we might still believe that some error had crept in, but they all came to the same results within a difference which was only a small fraction of what they were trying to eliminate. The reason why these fractions appeared in the atomic weights of so many elements had to be sought elsewhere.

Then there was something else. Hydrogen, being then the lightest known element, as it is yet, was given the atomic weight one. Oxygen had a weight slightly under sixteen. A little manipulation of the atomic weights showed that there would be more elements with atomic weights expressible in integer numbers if the figure for oxygen were made exactly sixteen, and this was done. The atomic weight of hydrogen now became 1.0078.

It had been suggested by Prout that perhaps all elements were built up out of hydrogen atoms. This suggestion was never accepted by the learned world and had to be given up entirely when it was found that the weight of hydrogen was not unity. And yet, so must the scientist change his viewpoint, that now, though we do not accept Prout's suggestion, we must agree that there was more in it than appeared on the surface.

Let us compare an atom of oxygen and one of helium. The first element has sixteen protons and eight electrons in its nucleus while helium has four protons

and two electrons. Four atoms of helium would make one of oxygen. However, this is not saying that they do. Then let us compare the helium and hydrogen atoms. It almost seems as if four of the one might make one of the other. If only the hydrogen atom had an atomic weight of exactly one, everything would go smoothly, and we could then say that all elements are made up either of helium alone or else of helium and hydrogen. For instance, oxygen would be made up of four atoms of helium, while nitrogen, with its atomic weight 14, would be made up of three atoms of helium and two of hydrogen.

The law of conservation of matter tells us that matter cannot disappear, and if we did not have to consider anything else, we would come to the conclusion that four atoms of hydrogen can never be the same as one of helium, for there is too much matter in these four atoms. However, we are not so sure any more of this law as we once were. We have seen that an electron moving at very high speed seems to have more mass than when it moves slowly. It acts as if its mass had been increased. It seems as if energy can be converted into mass and that the reason why we do not notice it in our daily lives is that the speeds we ordinarily observe are entirely too low to have any noticeable effect. When electrons are shot off with speeds of 100,000 miles a second or more, we find that speed and mass—or rather, energy and mass—effect each other mutually. If energy can be converted into mass, cannot mass be converted into energy?

It may well be that the four atoms of hydrogen, coming together to form one atom of helium, had some of their masses converted into energy so that each atom before the union had a mass of 1.0078 but that it was reduced to just one after the union. The fraction was changed into energy. As it is commonly expressed:

the packing together of the four atoms caused some of the mass to be lost, or rather to be converted into energy. This energy escaped in the form of radiation. Some time someone may be able to do this experimentally and then we shall have proof of this fascinating hypothesis.

We might say, if the foregoing were proven, that all atoms are built up of hydrogen, but there is a reason why it would be better to say that they are built up of atoms of helium and hydrogen. The reason is this: when the radio-active elements explode, they throw off atoms—or rather, ions—of helium and not of hydrogen, while a bombardment of the atoms of nitrogen develops some hydrogen. This would show that those elements which have an even atomic number may be considered as having been built up of helium bricks, whereas those which have an odd atomic number are made up of two kinds of bricks, the helium and hydrogen atoms.

The fact that we have not been able to compress hydrogen so that helium is formed should not make us think that it cannot have happened in nature. We have been able to make tiny specks of diamond, but, so far, we have not succeeded in making a Koh-i-noor. Nevertheless, we cannot deny that nature has done it.

We are very apt to think that a thing cannot happen simply because we are unable to do it, notwithstanding that we have made many attempts. I remember reading a book written by the naturalist and nature lover, John Burroughs. I enjoyed it very much, as one must enjoy reading of the thoughts and experiences of so gifted a man, gifted with a clear mind and a beautiful character. But there was one statement he made which showed that he, too, had some of the weaknesses of the ordinary mortal. He said that we humans would never be able to create a living thing, be it only the

simplest kind of cell, for it had been tried thousands of times and failure had been the result of every experiment. Without taking sides in the matter, without saying that it can or that it cannot be done, I wish to point out that the mere fact that we have failed proves nothing. It might have proved something if we had tried it as often as nature, but even then the proof would have been only a negative value. Nature has all the material for the making of a living thing in every drop of water of the oceans. She has a variety of temperatures, graded or shaded by infinitesimal intervals, and she has been making experiments with these materials for untold millions of years. It would be a wonderful piece of luck if we accidentally hit the exact mixture of materials and the exact temperature, not to mention the many other possible requirements in our paltry few thousand experiments. Nature has forces at her command which are so tremendous that we cannot hope to do all she can do. Once in a while we will have to be satisfied to consider possibilities without hope of making realities of them by experiment. The condensation of hydrogen atoms into helium may be one of these cases. On the other hand, it may well be that while I am writing this, some scientist is succeeding in doing that very thing.

Speculating about a thing does no harm, provided we remind ourselves from time to time that the result of our speculation is merely a possibility, and not the solid truth. Astronomers, like ordinary mortals, sometimes indulge in this pastime of speculating. It has been suggested by some of them that the conversion of material may possibly be the reason why our sun keeps on sending out energy eon after eon without any apparent reduction of power. They say that somewhere in the universe hydrogen is formed, that these atoms of hydrogen are gradually crowded together into helium,

and that in the process enough energy is set free to supply a star—our sun, for instance—with its seemingly inexhaustible energy.

Some go a step further and say that there is nothing in this world but energy. Some of it we know as such, and some we know as matter. I notice that the further I get with this book the less sure I am of anything. I have gradually come to that part of science where nothing is quite settled. And that is exactly what science is: a search for the truth. Things which have been established beyond the possibility of doubt no longer interest the scientist. He does not care for dogma. He never feels that he has arrived. Rather, he enjoys traveling and he feels sure that his next stopping place will be a very interesting one to visit.

CHAPTER XXIV

Light Work

TO most of us light is a sensation, nothing else. If we had no eyes there would be no light. You might say that there would be light whether we have eyes or not, for there would be other beings, animals who could see, and that therefore light exists, independent of our ability to receive and recognize it. Well, that is matter for philosophers to discuss. This much is sure: it would not exist for us. Radio waves existed long before we were aware of them and so did X-rays, but they did not exist for us. We simply had no instrument to make us aware of them. So it would be with light if we did not have the proper instrument to bring it to our conscienceness. We have been provided with such instruments, and now light exists for us to the extent that our eyes are sensitive to it. I believe I mentioned before that those eyes of ours are sensitive only to a very small part of what we may call light. Though we cannot see it, we speak of ultra-violet light. We may speak equally well of X-ray light, for once we provide ourselves with the necessary auxiliary eye, such as a camera, we can see X-rays and ultra-violet rays.

To the scientist light is that part of the scale of ether vibrations which affect the eye. To him it is no mere sensation. It is a form of energy and he expects it to do various kinds of work according to the kind of tools we give it to work with. If, for instance, we provide a little mill on which it can exert its force, it will drive that mill just as the wind will drive a larger one. You

can see these little mills in the show-window of many opticians. Give light other tools to work with and it will do other work.

When light strikes an object it knocks some electrons off the surface. As a rule, these electrons are not thrown off with enough force to remove them out of the range of attraction of the rest of the material. This knocking off of electrons may have different effects according to circumstances. It may cause a gas to become ionized and thus be made conductive; or, having made ions of some of the atoms of a material, it may cause these ions to combine with some other material. Then again, if the electrons are set free entirely, and have a chance to move to a positively charged substance, it may cause an electric current to start.

Exactly what takes place when light strikes the eye is not entirely clear, for it is not easy to experiment with eyes and brains. It may well be that the ends of the many nerves, terminating in the retina, are positively charged by light and that, as a consequence, electron currents are conveyed to the brain and there converted into what we call consciousness. Or it may be that the light has a chemical effect on the ends of the nerves; the reaction of the brain restores the nerve ends to their original condition, and this may, perhaps, explain why an impression remains in the eye a considerable length of time after the light has been removed. The different wave lengths of light, having different amounts of energy, may affect the nerve ends in different ways and so give us the impression of colors. All this, and many other things, may take place, but we are not sure just what happens and it must always be difficult to come to a perfect understanding.

It is not so difficult to understand what happens when light strikes the sensitive film of the camera. We

see a chemical action and we are familiar with other instances where energy applied to a substance causes it to combine with some other material or, in some cases, to separate itself from it. The energy may be in the form of heat or even pressure. We are also familiar with chemical action caused by light. It is going on every day all over the world. Light, acting on the green matter of plants, causes it to take up carbonic acid. Even if we do not know exactly how it all happens, we can at least speculate about it and make ourselves a fairly satisfactory picture of it.

The idea of free electrons, whether stationary or revolving around a solid nucleus, helps us here. We can see one or more of these electrons being struck by a light wave, or whatever it may be, and being moved away with such speed that it gets beyond the influence of the nucleus, leaving an ionized atom behind. We can also understand why one kind of light has such an effect while another kind has not. It all depends on the amount of energy of the particular kind of light. Red light with its long wave length and slow vibration has not enough energy to do much. Ultra-violet light with its short wave length and rapid vibration has a very marked effect. X-rays with their still shorter wave lengths and still more rapid vibration will do such work, even after they have passed through material which would entirely kill the chemical effect of other kinds of light. This explains why the red color of an object to be photographed shows about the same on the film as if it had been black. It also explains why the images of stars, which cannot be seen with the unaided eye, show brightly on a photographic plate. The starlight has a certain amount of ultra-violet rays which do not affect the eye but are the most powerful rays of all when acting on the plate.

Perhaps the most interesting action of light is its ability to establish a path for an electric current when it has been given the necessary facilities to do so. What is needed in the first place is some material which is sensitive to light, meaning that it should emit some of its electrons when a beam of light falls on it. There are a number of such substances, such, for instance, as the metals sodium, potassium, rubidium, and caesium. Many others are affected that way but in so much lesser degree that they are not used when we want to apply this property of matter to some practical purpose.

Another thing which must be provided if we want the electrons to establish an electric current is some device which prevents them from returning to the atoms from which they came. We have seen how this is done in a radio set, where the heat of the filament causes electrons to jump out of it. There we applied a positively charged plate which attracted the negative electrons and thus established a path for the current. We do the same thing when electrons are set free by the action of light.

The photo-electric cell is just such an arrangement of a piece of material which is readily affected by light and a positively charged plate. Next we must have a source of light, and this is easily provided for. Any light will do, but not all sources of light are equally valuable when we wish to apply the cell to some practical work. There are applications of the photo-electric cell which depend on ordinary daylight to do the desired work. Others require some artificial light, such as neon lamps, and still others need infra-red light which, like ultra-violet light, might be called dark light.

Whatever the source of light may be, the action of the cell is to produce a weak current which is fed into some device where it opens a valve or switch to estab-

lish a path for a larger local current. This process may be repeated until finally we have enough power to open the locks of the Panama Canal or raise a sunken warship. As a matter of fact, it has not yet been used for these purposes, but the system lends itself to it if it should be desirable to do so.

The photo-electric cell reacts instantly to the action of light, and we can therefore start or stop or modify a current as rapidly as we may wish to, provided we can turn a light on or off or dim it with sufficient rapidity. We turn on an electric bulb in our house and get instant action, as we probably think. When we turn the switch again, the light seems to disappear at once. As a matter of fact, there is an appreciable interval of time between the turning of the switch and the moment that the light has entirely disappeared. Our eyes are so slow in their action that they do not notice it. It is not entirely a disadvantage—this slow action of our eyes. We would not enjoy the movies if our eyes were much faster. The individual photographs on the film are taken at the rate of sixteen a second and are projected at the same rate. The movement of the film brings a new picture before our eyes every sixteenth of a second, but in this short time the film had to move so that we did not have a complete view of the picture during all of that sixteenth of a second. If our eyes worked instantaneously we would get the impression of a number of detached photographs and not the continuous, uninterrupted scenes we now enjoy. The eye retains an impression for about one-eighth of a second so that a scene on the film has not yet entirely disappeared before the next one is seen.

The photo-electric cell is somewhat like an eye in that it is sensitive to changes in the strength of light, but it is much quicker in its reaction. The interval of time between the moment it receives the light and the

moment it sets up a change in the electric current is so small that we have no way of measuring it. Practically speaking, the reaction is instantaneous. We also have a light which, so to say, is either on or off, which has no afterglow, and of which the intensity changes instantaneously with the strength of the current producing it. Such a light is the neon lamp, which has no filament to carry some of the heat, and therefore some of the light, after the current has been cut off. If, for instance, such a lamp is connected to a circuit of sixty cycles per second its intensity of light varies exactly as the strength of the current; in other words, this light attains a maximum of intensity one hundred and twenty times a second. There is just as often a complete absence of light. The ordinary filament lamp, as we know it, would not show these variations because our eyes do not act quickly enough. When the light is produced by a 25-cycle current, a certain amount of flicker is noticed. Just go to Buffalo and see. In the course of time your eye will get used to this effect and you do not notice it any longer. You may possibly meet someone in that city who has lived there all his life and is utterly unaware of the fact that his electric light flickers.

To come back to our neon lamp: it actually goes on and off 120 times a second and we can show this in a very pretty manner. We put a photo-electric cell opposite the lamp and connect it to a radio set where the small amount of current which was generated in the cell is magnified sufficiently to operate a loud speaker. You will hear a tone which corresponds to 120 vibrations per second. We may be several hundred miles away from the place where the electric current is being generated, but if we have a tuning fork which makes 120 vibrations per second, and we hear that the note of the loud speaker is not exactly that of the tuning

fork, we can say with absolute assurance that the generator in that remote place is not running at the correct speed.

We can use the small amount of current generated in the photo-electric cell in various ways. We can cause something to happen when there is such a current, or when there is no current. Let me give some examples of both systems.

Just imagine a little truck running on a piece of track. It is driven by an electric motor. Whether the motor is on the truck or at one end of the line or somewhere else makes no difference. The little truck is provided with a light, which is thrown in a parallel beam in a direction at right angles to the track. It carries a load of material which is to be dumped at a certain place along the track. We place a photo-electric cell there as well as the necessary apparatus to magnify the little amount of current which the cell produces. When the truck comes opposite the place where this cell is, the beam of light acts on it and a current is set up which may be made to do anything we wish. For instance, it can be made to stop the motor and, at the same time, start another motor which makes the car dump its load, and, when this is done, the current of the main motor may be reversed so as to bring the truck back to its starting point. The photo-electric cell may be placed where we wish to dump and its location may be changed when a new dumping place is needed.

Many of the present-day applications depend on the other system—that is, something is made to happen when the photo-electric cell is *not* struck by light. There is, for instance, the installation at the entrance to the bridge across the Delaware at Camden. This installation is for the purpose of checking the toll receipts. A car standing at the toll gate intercepts the light, which normally would strike a photo-electric

cell. Every time this happens, a mark is made on a record so that one can see at any moment just how many cars have passed.

Another application of this system is for the opening and closing of the doors between the pantry and the dining-room of restaurants. Every time a waiter passes under a light in the pantry, and near the door, the door opens and when he has come under a similar light in the dining-room the door closes again. Another application is for protection against burglars. This is perhaps the most interesting of them all because here use is made of the fact that dark light acts on the cell as well as ordinary light. Of course, it would not do to let the burglar know where he should stand to keep the cell from doing its duty and so one makes use of the infra-red light which is visible to the cell but not to the burglar.

An unlimited number of applications are possible. Street lighting in a city may be started when daylight has faded to a predetermined point. Display lights may be started when it is dark enough and shut off again when it is light again. Many other uses may be found for the photo-electric cell, but up to the present there is, perhaps, no more important application of the cell than in the talking movies and in television.

At the movie studio the actor says his lines in front of, or at least near, a microphone. His voice modifies the current, which lights a neon lamp. Strength of voice, pitch, and timbre, all have their effects on the current, so that the neon lamp gives light, which, in intensity, corresponds to the fluctuations of the voice. The neon light is focused on the film so that, when this film is developed, there appears a band of greater or lesser degree of darkness. It is darkest where the neon light was strongest and, thus, where the voice was strongest. The minutest changes of the voice are

represented by changes in the darkness of the film. At the receiving end, that is, in the theater, a beam of ordinary light is focused on the film and is reduced in intensity more or less according to the darkness of that part of the film it must penetrate. Whatever light comes through the film is received by a photo-electric cell and this sets up a current which can be used in the manner which is familiar to all radio amateurs to operate a loud speaker.

Television, too, is based on this power of the light waves to eject electrons. The future probably holds in store for us many other applications of this power. Many scientists and engineers are working on a number of possibilities, and when such a search is on there is almost a certainty that something will be found.

To say that light has the power to eject electrons is telling the story in headlines. The how and when and why must be known if intelligent use is to be made of this power. And thereby hangs a tale.

CHAPTER XXV

About Slot Machines and the Quantum Theory

SOMEWHERE in his book, "The Universe Around Us," Sir James Jeans says: "The problem of shifting an atomic system is like that of extracting a box of matches from a penny-in-the-slot machine; it can only be done by a special implement, to wit a penny, which must be of precisely the right size and weight—a coin which is either too small or too large, too light or too heavy, is doomed to fail."

We can go a little further with this simile. In some European and South American countries there are two classes on the trams. Let us imagine that we want to take a ride in one of these trams. We are at the terminal station and in order to enter the tram we must provide ourselves with a ticket. There is an automatic machine in the lobby, with two slots, one for dimes and the other for nickels, or whatever coins they have over there to purchase tickets for the first or second class. Put a nickel in the proper slot and the machine ejects a ticket for the second class. Try to put your nickel in the other slot and you'll find it cannot be done. Try to put a dime in the nickel slot and nothing happens, notwithstanding that the value of your coin is sufficient for two tickets. Your dime is lost. Again, put a dime in the other slot and you obtain a ticket for the first class, but you won't get two tickets for the second, although that is what you may have wanted to get because of having somebody with you. No number of nickels will ever produce a ticket for the first class

and no amount of dimes will ever give you a ticket for the second.

Something like this is going on in nature. Nature requires nickels for certain phenomena and dimes for others. Furthermore, though five pennies are just as good as a nickel at the grocer's they are not accepted as such in nature. Nature does not reject the pennies as useless: she gives you five of the articles, each of which you might have bought for a single penny, but she does not give you the article which she has priced at a nickel.

It is not just the ejection of electrons which is controlled this way. Any effect which radiation has on an atom seems to follow the rule that the atom will only respond to the stimulus of radiation if this radiation is of the proper kind, that is, of the proper frequency. All other frequencies are rejected as of no use to this atom. Strength of radiation has nothing to do with it. The faintest beam of the proper frequency will have some effect and the most powerful beam of a radiation of the wrong frequency has no effect whatever. If a faint beam of a certain kind of light is capable of ejecting ten electrons, then a beam of twice that strength can eject twenty electrons, but no other frequency can do it.

When we visited an atom we saw how an electron sometimes jumps from a higher to a lower orbit and that it then sends out some radiation. The frequency of this radiation depends on what orbit the electron came from and to which orbit it is going. The radiation is simply the result of the fact that it had more energy in the higher orbit than in the lower one. The difference between the energies the electron has in the two orbits is a fixed amount, and therefore the frequency of the radiation it sends out when it jumps from the one to the other is also fixed. If an electron jumps from a

lower to a higher orbit, it does so because in some way or other it has received the proper amount of additional energy from the outside. We would naturally expect that this amount is the same as what the atom would give out if the jumping took place in the opposite direction. This is actually the case, but the strange part about this business is that nothing happens when the amount of energy given to the atom is more than it needs. Come to think of it, this is not quite the proper way to express it. The amount of energy may be more than is needed but the frequency may not be. All this is very much like the behavior of the slot machine where one gets the first and second class tickets. The machine does not object to any number of nickels or dimes, but it will not give dime tickets for any number of nickels and no nickel tickets are ejected if dimes are put into the machine.

When an atom is struck by the proper kind of radiation, something happens. Sometimes an electron is made to jump from a lower to a higher orbit and sometimes an electron is completely removed from the atom. The kind of radiation required for this action depends on where the electron is. When the electron jumps from a certain orbit to some other, it gives out radiation—let us say yellow light. On the other hand, when this atom is struck by yellow light, electrons are made to jump in the opposite direction, and this jumping takes place whether the light is weak or strong. The only difference is that more electrons are ejected by strong light. However, it must be yellow light. Blue light has no effect. All this is very much like our slot machine. A single nickel will produce a ticket. Many nickels produce many tickets, but a quarter or even a bright silver dollar fails to produce anything. The slot machine requires certain definite

coins in order to be operative and it seems that radiation requires the same thing: such and such a coin for this kind of radiation and some other coin for another kind of radiation.

The German Professor Planck discovered this peculiar behavior of radiation as early as 1900 and he came to the conclusion that radiation is only obtainable and is only provided in definite packages. Such a package is called a *quantum.* Just as all our coins can be reduced to pennies, so all quantums of energy can be reduced to some fundamental unit. A quantum of energy consists of the product of a constant amount multiplied by the frequency of the radiation. For instance, a quantum of red light is much smaller than one of violet light, and that is so simply because the frequency of violet light is much greater than that of red light. In other words, red light has less energy than violet light and the photographer is well aware of this fact, for he does not hesitate to expose his photographic plate to red light when he is developing it, whereas he knows very well that exposing it to any other light would spoil it.

This also explains why it is so difficult to obtain a photograph with correct light values. Though a red object may appear very bright as seen by us, it appears almost the same as a black object on the photograph, whereas the parts which are colored violet, though rather dim, seem very bright in the picture. The colors beyond the visual spectrum (if colors we may call them) have still more energy. The amount of energy of a radiation is directly proportional to the frequency of the radiation. Ultra-violet rays have more energy than any of the visible colors and X-rays are still more powerful.

A quantum of energy is a very definite amount. As I said before, the amount is equal to a constant multi-

plied by the frequency of the radiation. The light we receive from the sun consists of a great many different radiations, but each one of these is made up in definite packages. There are no half packages. In former years we could buy our oatmeal at the grocer's in any quantity we wanted. If the amount he scooped out of the bin was not exactly what we wanted we could tell him to give us a little more or a little less, but nowadays we buy the oatmeal in packages. We can buy one package or we can buy two, and perhaps (for I am not very well acquainted with the trade in oatmeal) we can buy a large package or a small one, but we cannot buy a fraction of a package.

It is as if the sun were shooting bullets at us. They all come with the same speed, the speed of light, but the bullets are not all of the same size. Some are large and some are small and the damage they cause is proportional to their sizes. These bullets hit some of the atoms, and right here is where we must drop the simile of bullets hitting something. It makes no difference whether a bullet hits a man or a woman or a child or some animal; the bullet does its work equally well. But the bullets the sun or any other radiating object sends out must hit the proper kind of victim or else there is no result at all. It is somewhat as if a shrapnel could only kill an artillery man, while a rifle bullet is needed to do damage to an infantry man. A quantum of energy may be just the right amount to lift an electron from orbit three to orbit five, but it will not be able to lift one from orbit one to orbit two.

There have been a number of disturbing discoveries since the beginning of this century. There was, for instance, the discovery of radium which threatened to upset the well-established law of the preservation of energy. Here was a natural perpetual motion machine. This was contrary to everything we knew and believed.

Then there was the discovery that the electron had more mass when it moved at a high rate of speed than when it was moving more slowly. This upset the law of the preservation of matter. And finally there is Planck's theory which tells us that energy is atomic in structure—that is, that it cannot be indefinitely divided. It comes in definite amounts, and the fact that these amounts are very small does not help us. Matter also comes in very small units, the atoms. We are more or less accustomed to consider matter as being built up of definite, indivisible units. Even the old Greek philosophers had an inkling of this and we have had several centuries to get used to the idea; but that energy also should be furnished by nature in definite and indivisible amounts is so contrary to our subconscious ideas that it required very substantial proof before even the most open-minded scientists could accept it as the probable truth; and even now, although all the testimony at hand points to the fact that the quantum theory is correct, there are some points which require further clearing up.

If a beam of light is a succession of small bundles of energy and not the result of a succession of waves, then the Huygens wave theory must be dropped and we will have to come back to the Newton idea that light is the result of an object being struck by corpuscles moving at the speed of light. Science is not ashamed to acknowledge that it has gone astray and that it must reverse its former judgment, and it would do so in this case, except that then we would once more be confronted with the difficulty which once made the Newton theory untenable, and that is the interference of light. If an object is illuminated by being struck by corpuscles or bundles of energy or anything else, then the more of these things that strike the object the more it must be illuminated. There

would be no possibility that light added to light would cause darkness and this is just what happens when two beams of light differ by half a wave length. To satisfy Mr. Planck we must have corpuscles or something like it, and to satisfy Mr. Huygens we must have waves, and it would seem at a first glance that we cannot have both at the same time; yet it is being suggested, in quarters where we may expect considerable knowledge and logical reasoning, that the little bundles of energy may have the quality of waves or something closely resembling it.

Any kind of radiation striking any kind of material has some kind of effect. What that effect is depends partly on the kind of radiation and partly on the kind of material. We are familiar with the fact that some materials reflect light while others absorb all or most of it. A perfectly reflecting surface, if there is such a thing, would return all of the radiation; a perfectly absorbing material would return none of it. Lampblack comes very near to being such a perfectly absorbing material. What becomes of the radiation when it is absorbed?

There are all kinds of radiations, but in the final analysis they differ only as to their frequency and, therefore, as to wave length. Temperature radiations, heat, have relatively great wave lengths; visible light has shorter wave lengths, ultra-violet rays still shorter, X-rays very much shorter yet, and gamma rays the shortest of them all if, for the moment, we forget the cosmic rays about which so little is known at the present.

When an object is struck by temperature radiations it may be warmed by them or it may reflect them or it may do partly the one thing or partly the other. That it is heated means that the molecules have been given additional motion. If the object is struck by visible

light, it may again reflect some of it and absorb the rest. Visible light may consist of a number of different radiations, some of which may be of sufficiently low frequency to affect the molecules and warm the object. We are well aware of the fact that the lower part of the spectrum, the part toward the red, is warm. However, there are also radiations of frequencies too high to affect molecules. These radiations act on the atoms by lifting some of the electrons from a lower to a higher orbit. They may also do something else besides, as we shall see presently.

X-rays have such a high frequency that they are able to eject some of the electrons from the body they strike, and gamma rays have this power to a still greater extent.

There is no definite line of demarkation as to where one of these actions ends and the other begins. Visible light, for instance, has also the power to eject electrons. If it did not, there would be no photography.

Dealing with objects and phenomena which we can never observe individually and in detail, it becomes necessary to stop once in a while to build ourselves a model which we can visualize. We must try to compare the hidden things with facts and phenomena with which we have become familiar in our daily lives. However, when we do this we must never forget that no simile is entirely correct. So, for instance, when we want to get a better understanding of the action of quanta of energy acting on the oscillating electrons of an atom, we may visualize it in the following manner:

Someone is sitting in a swing and someone else is standing behind it. The latter person pushes the swing and sets it in motion. Every time the swing reaches him on its backward movement, he gives it a push and so keeps the swing moving or, perhaps, increases its movement. To do this he must time his movements

with those of the swing. If the movements of the swing and the man are not in synchronism, the effect of his pushes is lost. We may now imagine that the oscillating electron is the swing and that the quanta of energy strike the electron at regular intervals. If there is synchronism, the electron takes up the energy; if there is not, the electron remains unaffected.

However, our simile, like all similes, was not entirely correct. We can imagine that the man behind the swing gives a push at the end of two or three oscillations instead of at the end of every one. In that case the effect on the swing is still to increase its amplitude, though not to the same extent as when he pushes it at the end of every stroke. We might expect then that the quanta of energy might also affect the electrons if their frequency were half or one third of that of the electrons, but this is not the case. The frequency must be right or there is no result.

All this is true as long as the effect of the quanta is the changing of the orbit of the electrons. Similarly, the radiation given out by an atom when one of its electrons goes from a higher to a lower orbit produces a quantum of energy which has the frequency corresponding to the loss of energy of that electron. But there is another action which also can take place when radiation strikes an atom. To come back to our simile of the swing and the man pushing it. We can imagine that this man pushes the swing so hard that it flies off its moorings and sails along the veranda. This does not require that the push be in exact synchronism with the oscillation of the swing. All that is necessary is that the push be powerful enough.

Such sailing away of the swing—I mean the electron—takes place when the atom is struck by ultraviolet rays, or X-rays or gamma rays, and sometimes when it is struck by visible light. In the latter case

the atom must be so constructed that it is relatively easy for an electron to leave it. Some elements have such a construction and are, therefore, suitable for use in photo-electric cells. As was mentioned before, the metals sodium, rhubidium, lithium, potassium, and caesium are the favored elements for this purpose.

The radiations of higher frequencies, such as X-rays, eject electrons from any kind of material. Einstein has established the law which controls this phenomenon. He did this on purely mathematical grounds, but later experiments have shown conclusively that his law is the true expression of what happens. The law is simply this, that the radiation which results when an electron is knocked off an atom has a frequency equal to the difference of two frequencies; one being the frequency of the radiation which strikes the atom and the other the frequency which is required to remove the electron from the atom.

If, for instance, the frequency of the X-rays or the ultra-violet rays which strike an atom is 100 and a frequency of 90 is required to knock an electron off the atom, then the resulting radiation will have a frequency of 10. Of course the frequencies are much higher; in fact, they are so high that the figures expressing them would be confusing. When I said that the resulting frequency is 10, I said something which has no meaning, for an electron sailing through space has no frequency, because it has no vibration. However, this electron may strike some other atom on its travel and cause a radiation, and when that happens this radiation has a frequency as expressed by Einstein's law.

CHAPTER XXVI

A Balance Sheet

EVER since the beginning of this century, and even before, new discoveries have been piled on new discoveries, new ideas on new ideas; old conceptions have been discarded or modified; and, as a result, our scientific business is in rather a confused state. However, this much is sure: the business has been very profitable. A statement of our assets and liabilities is in order.

An entirely new department, quite complete, has been added to our business—the department of radioactivity. At first, this addition seemed to be a loss rather than a gain for it threatened to undermine the very foundation of the business: the law of conservation of energy. However, this difficulty has been overcome, for it was found that the old law was as good as ever.

Then there was the discovery that electrons moving at high velocity had more mass than when they were moving at a slower rate. This upsets the old and well-established principle of the conservation of mass. To explain this, we had to assume that mass was partly, or perhaps altogether, energy. It is suggested that there is nothing but energy and that we recognize it as such when it is in motion, but that it appears to us as mass when it is at rest. This would mean that when we see a pound of substance, any substance at all, we should be able to express it as so-and-so much energy. Based on what was found to be the relation existing between mass and energy and velocity, Einstein

developed a formula which gives the amount of energy which would be let loose if mass could be converted entirely into energy. The amount is astonishingly large. You can read in various books how much it would be, but the figures do not mean much to me and probably would not to you. Someone has figured out that a piece of material the size of an ordinary pebble, when completely converted into energy, would be able to drive the Mauretania clear across the Atlantic and back again. The exact size of an ordinary pebble was not stated, but whether it is the size of a hazel-nut or of a walnut does not make much difference to us. In either case, the room devoted to fuel on the steamer could be very small compared to what it is now. It is pleasant to dream of the tiny bit of material we would need for heat and power in our homes; but on the other hand, we would have to be very careful lest it get lost or mislaid.

Apart from the fanciful dreams which can be woven around the idea of converting material into energy, and especially apart from the fact that we have at the present no practical way of doing it, the idea is of some use to us for it has solved a riddle which has troubled the scientific world for a good many years. The trouble was that the estimated age of the sun and that of the earth did not check. The methods used for these two estimates were based on entirely different principles, and the result reached was that the earth was very much older than the sun, which was, on its face, a foolish conclusion.

There were two main methods of estimating the age of our earth. One was based on the fact that much of the surface consisted of deposits laid down year after year by rivers, or floods, or some other action of the water. The depositing of solid material is still going on and it was, therefore, possible to find the

average amount of this yearly deposit. Comparing it with the total amount as found in certain layers of rocks gives the age of our little world by the simple operation of dividing the one into the other. Of course, there were a number of things to consider which I have not mentioned and which I have no intention of mentioning, for it is with the general method that we are concerned and not with the details. A quite respectable age was found as the result of this method. A much better and more reliable method was developed when we became acquainted with radium and its behavior. As we know, it was discovered that uranium is the grandfather of radium and that it, in its turn, is the grandfather of lead. The rate of decomposition of uranium into radium was known as well as that of radium into lead, so that we also knew the time required for the change from uranium into lead. The rate at which this change takes place is always the same. I mentioned that this rate is indicated by giving the average life of the radio-active material, by which we mean the time required to reduce the power of the material to half its original amount.

Wherever uranium ore is found there is always a certain amount of lead mixed with it, and by determining the ratio of the amounts of the two elements we can find how many years must have elapsed to produce this particular mixture.

It might be suggested that this lead did not come as a product of the uranium, but fortunately this lead has a different atomic weight from the lead of commerce.

The calculation is simple enough, but not quite so simple as it appears on the surface. If, for instance, we know that the average life of uranium is two billion years, and we find that the proportion of uranium and lead in a piece of ore is three of uranium and one of lead, we might be inclined to think that we have an

indication that the uranium is just at the half-way point of its average life, but this is not so. As two or more billions of years is rather a disturbingly high figure, we will take the liberty of imagining that the average life is a hundred years. We will further imagine that we have found a piece of ore in which there are three pounds of uranium and one pound of lead. We will now make the mistake of thinking that the life of this piece of material is fifty years. Our mistaken reasoning is that, as it takes one-hundred years to reduce half the amount of uranium to lead, it must have taken half that number of years to reduce one-fourth of the original amount. Let us see what this would lead us to:

Fifty years were required to reduce one-fourth of the amount of uranium, and therefore it must take fifty years again to reduce the remaining amount by one-fourth. The remaining amount is three pounds, so that, after another fifty years, three-fourths of a pound will be reduced, leaving at the end of a hundred years three minus three-fourths pounds of uranium. But this is two and a quarter pounds, and not two, as it should be according to our supposition that the average life was a hundred years. It takes a little mathematics to get the correct answer, but not enough to embarrass a graduate of an engineering college, provided he has not forgotten what he has learned—which, by the way, is not at all an uncommon occurrence.

There is more to this little problem than has been pointed out so far, for in this piece of ore which we are considering, there is not only some uranium and some lead but there are also all of the intermediate products, such as radium. Each of these products has its own average life, varying from hundreds of years to a few seconds. The problem is a complicated one, but all the data are at hand and scientists have solved more

complicated problems than this one and we may safely trust them to find the answer with a fair degree of accuracy.

This latter method is far more reliable than the first one, for it is not possible to say with certainty that the rate of deposit of the material which made the rocks has been at all times the same as it is now, whereas the rate of disintegration of uranium does not vary. The result arrived at is that our earth is of a venerable age. The answers given by different scientists agree with each other within reasonable limits. They range from fifteen hundred to two thousand million years. Though we might expect a widely different amount when the other method is used, as a matter of fact, the estimated age is about the same. I can almost hear someone say that answers which differ by as much as five hundred million years do not amount to much. We would not be satisfied with a system of bookkeeping which tells us that somebody owes us an amount somewhere between fifteen hundred and two thousand dollars. True enough, but in a case like this we do not say that the answers agree but that they are of the *same order*, which means something like this:

You and I look at a large field and you say that it seems to be fifteen acres in extent, while I estimate it to be twenty acres. Our estimates are of the same order. They would not be if your estimate were fifteen acres and mine were half an acre. If two other men should come to the same conclusions as we, we should have a pretty good assurance that the truth lies somewhere between the limits or very near them. As we learn more about geological data or of the exact rate of disintegration of uranium, we shall bring the two extreme limits closer together. For the present we should have to be satisfied with what we have, and say that the age of the earth is about two thousand million years.

I have drifted away from the statement that the ages of the earth and the sun did not check. I had to do this, for without giving you those ages you would have to take my word for it, and that is more than I have the right to expect. As it stands now, I shall have to give you also the age of the sun and then you will be able to draw your own conclusions.

For many years scientists have puzzled about the rate at which the sun is pouring out its energy. The rate at which it does this could be easily ascertained, for the temperature of the sun's surface could be measured with the same degree of accuracy, or almost so, as that with which we measure temperatures here. Various possibilities were suggested. For instance, it was suggested that so many meteors and comets and things fell on the sun that its temperature was maintained, but it was soon realized that if this had been going on for more than two thousand million years, the sun would have to be enormously much larger than it really is. Another suggestion was that the shrinkage of the sun provided the heat. This also was a good idea until mathematics was applied, and then it was found that not more than a mere fifty million years could be accounted for. And so the thing remained a puzzle until it was discovered that matter can be transformed into energy, and that a very small amount of matter gives an enormous amount of energy.

Sir James Jeans gives some very interesting figures in his book, "The Universe Around Us." He says that every square inch of the sun's surface is in effect a searchlight of just about fifty horse power, from which we can calculate that weight is streaming away from every square inch at the rate of about a twentieth of an ounce a century, but, as there are a great many square inches to the surface of the sun, the total amounts to about 250 million tons a minute, or 360,000 million

tons a day, or 131 million million tons a year. This seems to be a large amount, and so it is, but compared to the weight of the sun it is only a small percentage, for, as he says further, at this rate the weight of the sun, two thousand million years ago, was only one eightieth of one per cent more than to-day. In other words, the sun weighed just about as much at the time this earth was born as it weighs now.

If the discovery of the conversion of mass into energy had not done any other good, it would at least have relieved us of the fear that the sun would give out during our lifetimes. On the other hand, we must not take for granted that the sun will continue to lose weight at the same rate as it gets older. Sir James Jeans figures that a million million years ago it weighed seven per cent more than at present, and that 7,600,000,000,000 years ago it weighed a hundred times as much as at present. It was very generous with its radiation when it was young, but is now more conservative, as befits maturity. As it grows still older its size will still further decrease; and, what is worse, its luminosity will decrease at a much greater rate than its size. For instance, when it has reached half its present size, its luminosity will be about one-eighth of what it is now. Life on earth will probably be extinct by that time, which may be in another few thousand millions of years. One consoling feature of this thing is that we shall probably not suffer by it.

I believe we may say that this discovery of the convertability of matter into energy has given us at least as much new material for thought as it has wiped out old conceptions.

These last thirty or forty years have played havoc with our well-established ideas of atoms and molecules. We had it all so nicely settled. Atoms were little hard spheres. Maybe they were not exactly spheres, but they

were hard in any case. Each little ball, or whatever it was, attracted its neighbor and this explained the cohesion so evident in solid matter. They were closely packed together in some materials and somewhat less closely in others. In any case, there was not much compressibility left. This close packing was the rule in liquid as well as in solid substances. In a liquid the molecules had such a large amplitude of movement that they could escape beyond the sphere of influence of their neighbors and could sail along within the confines of the vessel that held them. If there was a weak spot in the walls of that vessel, say the open side of the top, they even had a chance to escape altogether. The entire theory worked very well; and let me say right here that we have kept most of it so far. But the atoms are no longer hard little balls. Everybody is agreed nowadays that the atom is mostly empty space. As Eddington expresses it, if all the real substance of a man could be compressed into one little wad, it would be difficult to see it under a strong magnifying glass. All the rest of his make-up would be emptiness. We have often noticed emptiness about some people, but, even in the worst cases, we would not have dared to think that it was as bad as all that.

If only all scientists would or could agree as to just how an atom is constructed, we could lay our heads down in peace, knowing that we would find the atom the next morning just as we had left it the night before. This is not the case. The atom is still in the condition in which the automobile was a few years ago. Every year new features were added or objectionable ones were removed. Scientists seem to compete with each other, each one trying to sell his own make of atom. They are all good, but none is perfect. They all construct the article out of the same materials, and as far as this goes there is nothing to choose between

them; all use electrons and protons, but some have their electrons stationary and some have them moving.

Those with the stationary electrons are very desirable when we wish to explain the chemical behavior of the elements, but they do not help us much when we desire to explain the how and wherefore of radiations. On the other hand, the kind with the moving electrons are not all we can desire when we wish to explain chemical action. As a whole, the moving system seems to have a little the better of it, but if this were a business proposition instead of a scientific problem, a conservative banker would hesitate to put money in the concern, for the future does not look any too encouraging. Professor Planck's quantum theory does not seem to fit either of the atom systems, and yet we must connect it with the rest of our knowledge in some way or other. This predicament makes one think of somebody who has taken a machine apart and reassembled it and now finds that he has a piece left over which he cannot place.

However, against the quantum theory, which has caused some confusion, we can mention certain other things which have been discovered and which remove uncertainty and confusion that existed heretofore. There was, for instance, the condition that there were so many elements of which the atomic number was not an integer, whether hydrogen or oxygen was taken as the base. The discovery of isotopes seems to have settled this problem fairly well. So far as experimentation has gone, the thing is settled and there is no reason to believe that further research will not have the same positive results.

There was—or perhaps I should say there is—still another point which could not be explained with the knowledge at hand before the discovery was made that mass and energy are the same thing. If hydrogen is

taken as the unit for atomic weights, most of the other elements have fractional weights, and if oxygen is taken as the unit, then hydrogen has a fractional weight. The latest suggestion is that certain elements are made by bunching some hydrogen atoms together and that, in packing the protons into a small confine, some of the mass has been converted into energy. For instance, four atoms of hydrogen are supposed to make one of helium. Other elements might be built up of more hydrogen atoms but it seems more likely that, if they are built that way at all, they are made up of hydrogen and helium atoms. Nitrogen, with an atomic weight of 14, might be the result of the packing together of three atoms of helium and two of hydrogen. Similarly, carbon, with an atomic weight of 12, might consist of three atoms of helium.

One of the difficulties about this idea is that four times the atomic weight of hydrogen does not make the atomic weight of helium. However, this very difficulty led to the solution of another mystery. It gave us an idea of what might be—at least in part—the cause of the energy or radiation of the stars, our sun included.

If we take the atomic weight of oxygen as 16, then the atomic weight of hydrogen is 1.0078. The weight of four atoms of hydrogen, therefore, would be 4.0312. However, if these four atoms are made into one atom of helium their combined weight would be only four, so that more than three-fourths of one per cent of the total weight would be lost. The assumption is that this lost weight would have been converted into energy and, as we have seen, a small amount of mass accounts for an enormous amount of energy. The four protons of the four atoms of hydrogen are supposed to have been packed close together and in this act of packing part of the weight has been lost, or rather, has been

converted. This thing may be going on in the stars. Furthermore, entire atoms may be converted into energy under the influence of the inconceivably high pressures and temperatures found in the stars. Such temperatures and pressures are beyond the limits of what we may hope to obtain in laboratory experiments. However, the result is not beyond what we can observe here on earth. When a piece of radium disintegrates we might expect that, at the end, the products of this disintegration should weigh as much as the original piece of radium. But this is not the case. Some of the weight is lost but, on the other hand, a large amount of energy has been developed.

Last, but not least, there is the relativity theory, with its fourth dimension, its curved space, its finite but unlimited universe, and other conceptions of an entirely new and radical nature. Some of these conceptions are such that we cannot visualize them, and this makes many good and honest citizens believe that they are unthinkable and therefore foolish. This is a rather short-sighted view, for there are things which we can picture to ourselves, but which are against all reason; and, on the other hand, there are many things which we can reason out to our perfect satisfaction but of which we are unable to form a mental picture for ourselves.

CHAPTER XXVII

The Fourth Dimension without the Spider

THE fourth dimension has been the subject of a great many conversations and a number of articles and booklets, some quite witty but mostly just funny. All of these articles and booklets, at least those published before Einstein came out with his relativity theory, were based on the idea that the fourth dimension was something like the other three—that is, it was something which could be measured with a yardstick.

Some of the essays started with an imaginary two-dimensional world. The creatures in such a world would see only the edges of other creatures or things. Of course, they could not picture to themselves how there could be another kind of world with three dimensions. In one of the booklets on the fourth dimension a ball is introduced. It rises and intersects the plane of the two dimensional world and one of the creatures in that world living on, or rather, in, that plane, sees the ball. Naturally what he sees is merely a circle, the intersection of the ball with his plane. The ball and the two-dimensional creature have a conversation in which the ball tries to give the other an idea of three dimensions. He does not succeed. All the creature can see is a circle. The ball rises, and calls attention to this fact; but the other creature does not understand the word *rise*. He has not seen the ball go up for he has not the necessary senses to see anything in the third dimension. All he has seen is that the circle has become larger in diameter. The writer comes

to the conclusion that, as we have only the necessary senses to see three dimensions, we shall never be able to see the fourth one, but this is no reason to think that there cannot be a fourth.

He points out that we do not see a body, we only see its surfaces and we need other experiences and some reasoning to come to the conclusion that there is an object with three dimensions and not merely a surface. When a cube is placed before us we see only some of its surfaces; but we have had some experience with cubes and similar objects. From the fact that not all the parts we see are equally illuminated, and from our experience with our finger tips, we reason that the thing we see must be a cube. In other words, though we see only two dimensions, we have the necessary mental equipment to build up a three-dimensional picture. If we lived in a four-dimensional world, we would see only three dimensions, but we would understand the real structure of the four-dimensional things. We would see the inside of the cube—whatever this means.

Others, less mathematically inclined, believe that we shall live in a four-dimensional world after our departure from this earth. It is the spirit world. The reason why we cannot communicate with the spirits is the same as the reason why the ball could not make itself understood by the two-dimensional creature. This last idea of the four-dimensional world, though not so well-worked out as the first one, is of much more practical value to mediums. It is, perhaps, the only idea on the fourth dimension which has monetary value.

It was pointed out in the second chapter that the fourth dimension of the relativity theory cannot be measured with the yardstick. It is merely the fourth element required for the exact definition of an event in nature. It is the answer to the question "when," whereas the other three answer the question "where."

It was further pointed out that neither the when nor the where were entirely independent of each other. There is a relation between them which can be expressed by a mathematical formula and Einstein gives us such a formula in his theory.

In Fig. 23, *M* is a point in the plane of the paper. *OX* and *OY* are two lines drawn at right angles through the point *O*. If we know the lengths of the two lines *MA* and *MB*, which are drawn at right angles to the two lines *OX* and *OY*, we can calculate the distance from the point *M* to the point *O*. In order to do this we square the lengths of the two lines *OA* and *OB*, add these squares together and extract the square root of this sum. The result is the length of the line *MO*. We might have drawn two other lines through the point *O*, again at right angles to one another, in which case the lines *MA* and *MB* would have had different lengths, but the result of the calculation would have been the same, namely the true length of the line *MO*. We might have drawn these lines *OX* and *OY* at some other than a right angle to one another, and in that case we would have to know the number of degrees of that angle before we could carry out our calculation, but the result would have been the same again.

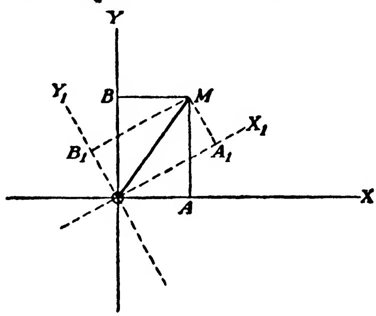


FIG. 23.

In Fig. 24 a point *M* is shown in relation to three planes at right angles to each other. Lines *MA*, *MB* and *MC* are drawn at right angles to these three planes. Here again we can calculate the length of the line *MO*. In this case we must square the three given dimensions,

add these squares together and extract the square root. Just as in the other case we can take three other planes through the point O, either at right angles to each other or at some other angle, and we still can calculate the length of the line MO, provided we know the various angles. We might even have drawn the three planes going through some other point than the point O, and, given the necessary information, we could again have carried out our calculation.

Now the relation between the three dimensions dealing with space and the one which has to do with time is this: that, in order to find the relation of some event to the point O, we must add the sum of four squares, three of which are the squares of the three lines, such as are shown in Fig. 24, and the fourth one the square of the time multiplied by the square root of minus one. Here we strike a difficulty, for there is no such thing as the square root of minus one.

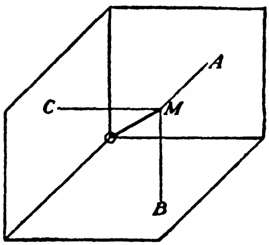


FIG. 24.

The square root of a number is that quantity which, when squared, gives the given number. For instance, three is the square root of nine, because when three is squared we get nine as a result. No number whatsoever will give minus one when it is squared. A number such as $3\sqrt{-1}$ is called an imaginary number. It is perfectly proper to object to the introduction of imaginary things into science, and especially into mathematics. I presume I shall have to show that although $3\sqrt{-1}$ is called an imaginary number, it is not at all an imaginary thing.

Ordinarily we do not realize that there is a certain amount of preparation required and that we have to make a certain number of assumptions when we carry

out even the simplest mathematical operation such, for instance, as a plain addition. Yet this is the case. Try to add three horses and four cows. What is the result? It cannot be done. We must first reduce the cows and the horses to something else, say quadrupeds, or vertebrates, or animals, or things, before we can do this little sum. Could we have found the result immediately if we were asked to add three black cows and four red cows? Again it cannot be done, because the three cows are black and the four are red. Even if they all had been black we would be up against the fact that some are big and others are little. We can only carry out our addition if we are willing to ignore all differences and only consider the similarities. There is no mathematical symbol which will take care of the fact that some of the animals were cows and some horses, or that some were red and others black. However, there are symbols which will take care of some other dissimilarities.

Let us take this simple problem: I walk three miles north and then two miles south. What is the result? The answer may be five miles or it may be one. If I am willing to forget the difference in direction the answer is five, but if I am not willing to do so the answer is one. Here is a case where I can add things which are not similar by introducing a mathematical symbol—the minus sign. However, this minus sign does not stand here for subtraction. Here it indicates the fact that the one direction was the opposite of the other. It gives us a clue to the final position. We find that every time one direction is the opposite of another one, and we have to add the distances traveled in the two directions, we may act as if we were asked to subtract the one from the other.

This little trick no longer helps us when two directions are not opposites. If I should walk, first three

miles in the direction northeast and then two miles west northwest, I would still be able to find the total number of miles I have walked by simple addition, and I could still calculate how far I would be from the starting point—that is, along a straight line—but it could no longer be done by simple addition or subtraction. The ordinary symbols we use in arithmetic do not help us here. However, we might invent a new symbol. In order to be of use such a new symbol must be one that allows us to use the common mathematical operations, such as addition, subtraction, multiplication, etc.

In Fig. 25 a right angle triangle is shown with the right angle at *C*. A well-known property of such a triangle is that the square of the line *OC* is equal to the product of the lines *OA* and *OB*. If *OA* is one and *OB* is also one, then the line *OC* is likewise one. Of course, when we say that both lines *OA* and *OB* are one, we take no account of the fact that they run in opposite directions. If we wish to do so we must call the one plus one and the other minus one and then their product is minus one. We find for the length of the line *OC* the square root of minus one, which, in this case, simply means that the length of the line is one and that it stands at right angles to the other lines. If we adopt this symbol, namely $\sqrt{-1}$, as indicating that a line is at right angles to some other line, and if we then carry out all kinds of calculations, we find that in all cases we obtain the same answer as if we had followed the more complicated way. And so we may say that, though there is no such number as the square root of minus one, yet we may use this symbol and feel sure that we shall obtain the correct answer.

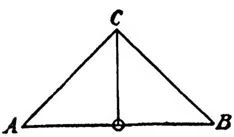


FIG. 25.

When Einstein introduces the fourth dimension in this manner, he does not say that there is such a thing as $\sqrt{-1}$ nor does he say that there is a direction possible at right angles to our three dimensions, but he does say that, multiplying the element of time by this imaginary number, he can carry out all of his calculations by the use of ordinary mathematics and he will find the correct results.

Things are different for me than they are for the man on the far away star, and it seems almost impossible for the two of us to come to an agreement. The element of time is the disturbing factor. Einstein's formula makes it possible for the two of us to agree, for, as the scientist says, this formula places the event we are observing in the same *frame of reference* for both of us.

Speaking of the relativity theory, one might well ask, "What is at the bottom of it?" We have seen that two people might observe the same phenomenon, come to different conclusions, and yet both be right. But why is it so? What is the foundation, the underlying principle?

The relativity theory is based on the facts that it is impossible to discover absolute motion or rest and that the speed of light is constant. We are rather familiar with, if not always conscious of, the fact that we cannot discover absolute motion or rest. You are looking out of the window while sitting in a train which has stopped at some station. You see another train on the next track. After a time you feel your car shaking slightly and you see the other train moving away—or perhaps it is your own train that is moving. You look out of the opposite window and you see that the station building is still where it was. Your mind tells you that it must be the other train which has started. The conclusion was easily reached, for you know that the building does not move.

For many centuries people have looked at the sun, the moon and the stars and noticed that all of them described circles around the earth. In addition, some of them had some extra motion. They were the planets. Our earth was the stationary thing. The telescope was invented and it was seen that all the stars had some additional motion. All of them described tiny circles, once a year, and certain ones had still other motions—some this way and some that way. As far as our observation goes all of this is quite correct. We are standing still and the rest of the world moves. An astronomer on some star sees that *his* star is the only stationary thing while all the rest moves, our earth included.

Which one is right, our own astronomer or the one on the star? Our planetary system, the sun, we, and the rest of the planets, appear to drift through space. Or is it, perhaps, that we are standing still and that the rest of the universe is traveling? The relativity theory starts out with the assumption that it is not possible to distinguish between the one and the other. The effects would be the same. We must have something besides our observation of the stars to be sure about their movements. There was no stupidity in the idea that the sun revolved around the earth—only a bit of egotism. What we needed was an apple to fall on Newton's head—if it ever did. We needed the laws of gravitation before we could say with certainty that all were moving—that is, moving in relation to each other—but there is no possibility of pointing out a single point in space which is stationary. Stationary in relation to what?

We have also made the acquaintance of the second assumption, namely, that the speed of light is the same everywhere and under all circumstances; that is to say, the speed of light in a vacuum. This is not such

an easy conception as it may seem. Somebody is standing a little distance from me. He lights a match and that light comes to me with a speed of 186,000 miles a second. If this man were moving toward me while he is lighting his match would that light come to me with the same speed or with the regular speed of light plus the speed with which he is walking?

Michelson and Morley have answered this question for us. The light comes to me with the same speed whether the man stands still or whether he walks toward or away from me. Michelson and Morley did not experiment with a slow-walking man but with the earth moving at the rate of nineteen miles a second.

This fact that the speed of light is the same under all conditions of rest or movement of the light-giving body leads to remarkable conclusions. We have already seen that we are compelled to assume that the length of a body is shortened when it is in motion in the direction of that length. Strange as this seems, various experiments have proven it. Moveover, we do not have to depend altogether on direct experimentation. In 1873 J. Clark Maxwell developed the electro-magnetic theory of light. His theory was later experimentally proven by Hertz. This theory showed that light follows the same laws as electro-magnetic phenomena.

Any piece of material consists of electrons and protons which are or have electrical charges. Move the piece of material and the electrical charges move, which is to say, there is a current of electricity, for an electrical current is nothing but a moving charge. Where there is an electrical current there is a magnetic field, and where there is magnetism there is attraction. Anyone doubting this can prove it to himself in a very simple manner. Take a dry battery cell

and attach a piece of heavy wire or a metal bar to one of the terminals. This bar projects horizontally from the cell. Now attach a piece of flexible wire to the end of the bar, but first roll part of the wire into a helix. The end of the wire is now attached to a switch. The other terminal of the battery is also attached to the switch so that we can let a current go through the helix whenever we close the switch. As soon as the current goes through, we see the helix shortening.

Such shortening must take place whenever we let a current pass through the wire, and it must take place equally well when we let a current pass through the elements of a piece of material. We can cause this to occur merely by moving it. We do not shorten the piece very much when we let it move with any of the speeds with which we are familiar—say with the speed of a railroad train or even with the speed of a rifle bullet. It is only when we employ speeds of thousands of miles per second that the shortening becomes measurable. A body would be reduced to half its length when it is moving with a speed of about 160,000 miles per second. The only objects which we can cause to move at such high speeds are the electrons and the alpha rays. These latter move with a speed of from ten to twenty thousand miles a second. The electrons in a stream of cathode rays move with speeds ranging from a mere fifty to as much as a hundred thousand miles a second, while the electrons shot off by a piece of radium acquire a speed approaching the speed of light.

It would seem to be a pity that we cannot carry out our experiments about the shortening of bodies in motion with more substantial things than electrons and alpha rays, but on second thought we see that we would be playing a dangerous game if we could

move the objects around us with such moderate speeds as, say, a mere 100,000 miles a second. Perhaps the best way to get an idea of what we would be playing with is to imagine that we are moving a small object weighing, say, the one thousandth part of a pound, but with a speed of a hundred thousand miles a second, and compare this with the movement of a two hundred ton locomotive going at the rate of sixty miles an hour.

The first thing to do, when we compare these two things, is to reduce the weights and the speeds under consideration to the same kind of units, that is, we will express the weights in tons and the speeds in miles per second. We find then that the locomotive weighs two hundred tons and the pebble, or whatever it is, the two millionth part of a ton. On the other hand, the pebble moves with a speed of a hundred thousand miles a second while the locomotive has a speed of the one sixtieth part of a mile per second.

The kinetic energy, which we may call the destructive capacity, in our case, can be expressed by multiplying the weight by the square of the speed. It is true that this is not the real energy, for we should have divided the weight by the acceleration of gravity, and we should have taken half the square of the speed, but as we should have had to do this with both the pebble and the locomotive, we took a short cut and did it with neither. These things would have canceled anyway. Carrying out our little calculation, we find that the destructive energy of the locomotive is $\frac{1}{18}$ and that of the pebble 5000. In other words, playing with a minute piece of material of which a thousand would go in one pound we meet destructive forces ninety thousand times as great as that of a two-hundred-ton locomotive traveling at a rate of

sixty miles an hour. We shall have to be satisfied to do our experimenting with electrons and alpha rays.

Just how much is a body shortened when it moves with a given speed? Much as I dislike to do it, I shall be compelled to give a mathematical formula here, for a sentence expressing what the formula does would become so long and complicated that it would be even worse than mathematics. So here goes: When the length of a body at rest is L, then its length when moving with a velocity v is expressed by this formula:*

$$L_1 = L \times \sqrt{1 - \frac{v^2}{c^2}}$$

In this formula c denotes the speed of light. The expression under the radical sign remains very close to unity so long as v is not very large. This means that a body is shortened exceedingly little unless its speed is exceedingly high. Let us see how much a railroad train is shortened when it is traveling at a rate of sixty miles an hour, or $\frac{1}{60}$ of a mile per second. Just substitute this $\frac{1}{60}$ for v in the formula and for c use the well-known amount 186,000. You will find that the train has been shortened to the amount of one part in a hundred and twenty-five million millions. It is apparent that we do not need to worry about the length of that train. But how about things that move around in the universe—such as our earth, for instance? In that case v would be 19 because that is

* Anyone interested in such things can find a very pretty demonstration of how this formula is derived in "Relativity and Space" by Steinmetz. He develops it directly from the two basic conception of the theory of relativity. These conceptions are:

1. The relative motion of the track with regard to the train is the same as the relative motion of the train with regard to the track.
2. The velocity of light in the train is the same as on the track.

the speed of the earth around the sun. We would find that the earth is shortened in the direction of its motion one part in ninety-six million, which is a little over five inches. Again we do not need to worry. All of the speeds with which we are familiar are so small as compared to the speed of light that there is no possibility of measuring the amount of shortening a body in motion undergoes. Even the motions of the heavenly bodies are too slow to show a marked effect.

The reason why ordinary speeds have no perceptible results is that the denominator of the fraction in the formula is so very large. Unless the numerator also is large the fraction is insignificant and becomes even less when we square it. However, when we make v large, say 161,000 miles per second, the value of the squared fraction becomes $\frac{3}{4}$, and therefore the value of the expression under the radical sign is $\frac{1}{4}$, so that the length of the moving body becomes one-half of its length at rest.

CHAPTER XXVIII

It Is About Time

I HAVE a friend who runs a railroad train. He and I have agreed to do some little experimenting. To make sure that we shall not misunderstand each other we have compared the various instruments we are going to use and have made the necessary adjustments so that, as an example, our watches are absolutely in accord. We set our watches at a time when my friend was 186,000 miles away. The manner in which we did it was this: He told me that, on a certain morning, at exactly nine o'clock, he would send me a light signal which, of course, would reach me one second later. As soon as I received this signal, I should set my watch to one second past nine o'clock. And this I did, so that we were now sure that our watches would tell us the same story.

My friend's train was 186,000 miles long, which is somewhat longer than present-day freight trains —though, if progress goes on as it has been going in the matter of the lengths of freight trains, the day may not be far off when trains of that length may be seen. Another peculiarity of my friend's train is its speed, which is 186,000 miles per second, a speed which exceeds by a considerable amount that of our passenger trains—local ones especially.

We have agreed that when his train is just 186,000 miles away from me, he'll give me a light signal, and that he shall give me such a signal every tenth of a second until he reaches me. We talked the matter

over, after our experiment was finished, and our conversation ran somewhat like this:

I said, "You did not live up to your promise. You said you would give me a signal every tenth of a second, whereas you gave me only one, and that one just as you were alongside of me. This experiment is worthless."

My friend became quite indignant and said, "I have lived up to my promise. I gave the first signal when I was 186,000 miles from you and thereafter a new signal every tenth of a second. The last signal was given when I was alongside of you. You probably were asleep all the time and only woke up when you saw me."

Neither of us being of the war-making variety, we decided to discuss the matter a little further and see if we could not come to some agreement. The conclusion we reached was that both of us were right and that, if we had only taken time to think, we might have expected the experiment to go the way it did.

At the time when he gave me the first signal he was one second away from me. (Think of the way the peasants in the old country indicate distances between villages.) It would therefore take one second for that signal to reach me but, as he was going at the same speed as the signals, he would arrive at the same time, so that I would see him and his signal simultaneously. He gave the second signal one-tenth of a second later. By that time he had traveled one-tenth of the road, so that there remained nine-tenths to be traveled. It took the signal nine-tenths of a second to reach me and, as one-tenth of a second had already past before he gave me the signal, this second signal reached me exactly one second after he had started—that is, at the same time the first signal reached me. The same reasoning showed me

that all the signals and the locomotive would reach me at the same time.

There was also a man standing at the rear end of the train—something which is very necessary in trains of that length. This man was told to flash a light at the same time as my friend the engineer. His flash reaches the engineer after one second, which is the precise moment when I see the ten signals, the locomotive and my friend. In fact, I see the engineer's back lit up by the brakeman's flash.

However, the brakeman gets to me just as quickly as his flash of light, and so I see the brakeman at the same time that I see the engineer. In other words, as far as I am concerned, the train has no length at all. I might have known this if I had taken the trouble to look at my formula, for it tells me that L is zero if v equals c. In that case, the square of v equals the square of c and so the expression under the radical sign becomes zero. But for my friend the engineer the length of his train is exactly the same as if it were standing still. For him the time between flashes of light was one-tenth of a second, but for me it was nothing. The real meaning of all this is that there is no possibility of a material object moving with the speed of light.

Once more I have to take back some of what I said. I said that I saw the flashes of light and the engineer and the brakeman, but as a matter of fact, I did not see anything at all. I can only see light, whether this light comes from an electric bulb or from a man who is visible because he reflects the light from some other light source. Light makes an impression on my eye because it is a succession of waves. If these waves have a length (that is, a distance between them) of anything between thirty-five thousand and sixty-three thousand to the inch, they affect my eye.

If they are shorter, they may possibly affect a camera, but I can no longer say that I see them. If they are longer, but not too long, I may feel them as heat.

Here I must refer you back to the newsboys who handed me hand-bills in the first chapter. The wave length there was first sixty a minute, and, when I began to walk, one hundred and twenty a minute. If the conditions had been so that all the bills reached me at the same time, the wave length would have been zero. This happened to be the case with the light waves which reached me from the train. All the waves reached me at the same time and therefore their wave length was zero. If the train had been moving with a speed a little less than the speed of light, the wave lengths would have been something, however little; perhaps the thousandth of an Ångström. They would have been cosmic rays, but, of course, entirely invisible to me and even to the camera. This is saying again that such things cannot happen in reality. Length has disappeared, and time has stood still. We have been dealing here with a *limiting case.*

Let us also see what happens when the train has passed me and the brakeman keeps on sending out light signals. We will suppose that the kind of light he uses is monochromatic light with a wave length of fifty thousand to the inch—yellow light, in other words. Though he is going away from me with an enormous speed, the light reaches me just the same and with the same speed as if he were standing still, for the speed of light is independent of the fact that the light-giving object itself is in motion. However, the number of light waves which reach me every second is not the same. We have seen that we can calculate the speed of stars from the amount of displacement of the lines in the spectroscope due to that speed. It is again a case of the newsboys and

their hand-bills, but this time I am walking away from them. At a certain moment the brakeman lets go a light wave. One fifty-thousandth of an inch later a second wave starts on its way. Meanwhile, the first wave has advanced a fifty-thousandth of an inch, so that the distance between these two successive waves is one twenty-five thousandth of an inch. In other words, so far as I am concerned, I receive twenty-five thousand waves to the inch. To say it another way, I receive a kind of light which has double the wave length of yellow light, and such light cannot affect the eye. It is heat, and not light, that I receive. Even if the brakeman had used violet

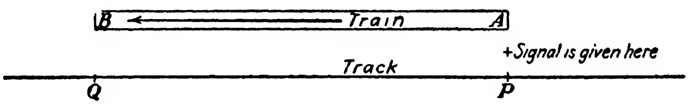


FIG. 26.

instead of yellow light, my eye could not have received it, for double the wave length of that kind of light is still below the visible range.

My friend the engineer and I have arranged for another set of experiments. This time we are going to use more common-sense speeds than in the first experiment. However, he will use the same train as before. Train and track are shown in Fig. 26. This diagram shows the train standing still alongside a piece of track of the same length as the train. The piece of track is indicated by the line *PQ* and is 186,000 miles long. We have compared our instruments and find that they agree perfectly. There are two observers in the train; one at *A* and one at *B*. There are also two observers along the track; one at *P* and one at *Q*. Our observations will be made when the train is in motion, going in the direction of the

arrow. At the precise moment that the point *A* is opposite the point *P* a light signal will be flashed at that point, which, of course, is seen immediately by the two observers at *A* and *P*. As the length of the piece of track is 186,000 miles, the observer at *Q* sees the signal one second later. The one at *B* would have seen the signal also one second later if the train had been standing still. However, in that second the train has moved so that it is a little later when the light reaches the observer at *B*. That is, it seems so to the man at *Q*. However, to the man at *B* the light is visible after exactly one second, for the light moves in the train with the same speed as on the track.

When the four observers come together to compare notes we find that they cannot agree again. Those on the train say that it took exactly one second to reach *B* whereas those on the track claim that it took longer. They claim that the clock on the train is fast, while the men on the train claim that the clock at the track was slow. However, when they compare their clocks again they find that they are in perfect accord and so they must come to the conclusion that time does not flow at the same rate on the train and on the track. To check the experiment they repeat it, but this time they place a mirror at *Q* and one at *B*. While the train is standing still they flash a signal and find that it takes just one second for the light to reach the mirror and one second to return to the starting point, and this is equally true for the train as well as for the track.

While the train moves, however, it takes more than one second to reach the mirror in the train, because the train moves in the same direction as the light, but on its return trip, the light does not have to go such a long distance, because now the train moves against the direction of the light. The men along the track

therefore come to the conclusion that the light moves at different speeds in the train depending on the light's direction, while the men on the train claim that it took just as long for the light to go one way as the other. And, what is still more confusing, the men on the train accuse those on the track of the same things which those on the track have claimed about the men on the train.

We must come to the conclusion that there is nothing absolute about time, just as we have found that there is nothing absolute about the length of a body. Time is relative. It depends on the relation of the observed event and the observer. It depends, as the scientist would say, on what frame of reference is taken.

When two sets of observers are moving in relation to each other, they are not in a position to agree as to the results of their observations, unless they consider the effects which their motions must have on dimensions, on time, on velocity, and even on mass. They must further remember that it is impossible to say that the one is in motion and that the other is standing still, for there is no way at all to make sure which one has moved. There is no such thing as absolute motion or absolute rest. We can only speak of relative motion, and, as a consequence, of relative rest. If there were a point somewhere which did not move at all, then we could make observations as to how the position of various things changed in relation to this point, and we could then speak of both relative and absolute motion. All things which are in motion would then have absolute motion in regard to this one point and all of them would have relative motion in regard to each other.

It was thought at one time that there was such a stationary point of reference. It was the ether. It

filled the universe and was at rest. Of course, if it filled the entire universe it *had* to be at rest; it could not very well go anywhere. Everything which was in motion sailed through the ether. It was a little difficult to imagine how this ether would go through a solid body, or rather, how a solid body could go through the ether and let the ether slip through the spaces between the atoms, but this did not prevent anyone from taking the ether for granted. At that time, the atoms were still little solid bodies quite close together, and the idea of the ether slipping through or between the atoms was not an easy one to visualize.

It is not quite so difficult nowadays. Our present idea of what a solid body is leaves so much room between the parts of which an atom is made up that it is easy to imagine almost anything slipping through. In fact, the real material takes up such a small portion of the space occupied by the body that we might almost wonder why one piece of steel does not slip through another. This knowledge of the structure of the atom did not exist at the time the stationary ether was taken for granted. We have seen how Michelson and Morley spoiled the game by showing that the speed of light was the same, whether we were going toward or from its source, so that the idea of the ether slip had to be dropped, and since that time we have been without a single point which we could call stationary.

It is rather bewildering to think of length, time, velocity and mass being relative. It does not become easier for us when we look a little further and find that we can no longer say that two things happen simultaneously, and that we cannot be sure any longer as to which event took place first and which second. It may well be that two things happen at the same time for one set of observers, while for another set

one event took place before the other. A third set claims that this second set of observers did not observe correctly, for what they claimed to be the first was really the second, and vice versa. All of them may have been right. The reason why these ideas seem so strange to us is that they are not based on our daily experiences. We may not be aware of it but we are constantly comparing new ideas or conceptions with the accumulated experience of our senses. After all, this is not to be wondered at, for all our knowledge is based on the impressions gathered by our physical senses.

Having rambled through science until we no longer know how tall we are, how fast we are going, what the time of the day is, or whether this or that thing took place first, I presume it is about time to come to the end.

CHAPTER XXIX

The End?

WE can come to the end of our ramblings, but science does not stop where we stop. It must go on forever. The time is past when there were learned men who knew all there was to be known. For many centuries humanity had been feeling its way along a long, dark, winding tunnel, never seeing the light of day. Then there came the time when a faint glimmer of light was visible far away. Man obtained a first glimpse of a world beyond that of his immediate needs, and he thought that this was all there was to be seen. The field was small and far away, and it was not easy to distinguish details, but man was not aware of this and thought he saw all there was in the world. He knew all there was to be known. Gradually, and very, very slowly, the tunnel widened and as it did so the field also widened and became clearer. But also, as more and more details could be seen, it became evident that there was much which could be guessed at but about which one could not be entirely sure.

At last there came a time when no one dared to say that he possessed all the available knowledge, and it was because of this that data and theories had to be classified and grouped. There was no longer one single science; there were sciences. Some advanced rapidly, some more slowly.

Physics seemed to do a little better than other branches of science. It had a good many facts to begin with. Other branches, such as astronomy

or botany, have had to collect much material before things could be systematized and an attempt made to connect one thing with another. It is true that some new departments, such as electricity, were added from time to time to the science of physics; but, as a whole, the physicist always had a large number of phenomena which he could arrange and compare. He was dealing with material things, things he could lay his hands upon, things he could experiment with in his laboratory. The astronomer is not so fortunate. He can only *see* the object of his study. The only sense impression he gets is through the eyes. The physicist can see and hear, feel, smell and taste his material. And so it is no wonder that physics was on a solid basis before some of the other sciences. It is rather surprising that astronomy, the science which deals with objects that never can come within our reach, should have been so far advanced; but this is due to the fact that the heavens, with their mystery, were always an attraction to the inquiring mind, and that a great many data could be collected with the simplest kinds of instruments.

It was not so many years ago that the average text-book on physics was divided into certain standardized sections. There was one, generally the first one, dealing with purely mechanical phenomena, such as air pressure, hydro-statics, and a few others. Then there was a section dealing with sound, then one about heat, one about light, one about magnetism, and finally one about electricity. However, even then, some of these sections were connected with some of the others, such as the one about electricity with one about magnetism. Resemblance between light and radiated heat was mentioned, but as a whole, each section stood by itself.

Neither astronomy nor chemistry had much to do with physics. Later on these three sciences came nearer and nearer together, and now each of them borrows from any of the others the material it needs to explain the phenomena within its own domain. It is no longer satisfactory that some theory shall explain things in one of these sciences. It is considered faulty if it clashes with what has been found in any of the others. Each one helps the other two. We explain the structure of the atom by what we know of the stars, and we explain the life of the stars by what we know of the atom. We connect electrolysis with chemical affinity, and both physics and chemistry are the richer for it.

The work of the scientist consists of a number of different things. He must collect data, he must classify them, connect them, find a cause for some new effect, or some effect of a cause he has discovered. It might be objected that he cannot discover a cause before he has found an effect, but he may have found some effect and recognized the cause of it, yet wish to find other effects of this same cause in order that he may feel surer that his theory is correct.

All these things were done in olden times as well as now. But scientific discipline was not very rigorous and the philosopher quickly got tired of the task of collecting evidence. He wanted to come to a verdict as soon as possible, and when he did not have enough evidence for a conviction he would manufacture some himself. As a rule, science, in the olden days, was a mixture of fact and fancy.

This is no longer so. Much material must be collected before classification begins, and when it comes to pronouncing the relation of cause and effect, every scientist watches every other one and checks him up, not with the malicious thought of tripping

up a competitor, but for the purpose of making doubly sure, so that thereafter all can make use of the new discovery without fear that, after all, the thing is not as it seems to be.

Above all, the present-day scientist measures. Weighing, measuring and calculating are the three most important methods of the present scientific era. Whenever possible, science tries to put some natural law in the form of a mathematical formula. The results of measurements of some new phenomenon must correspond to this formula—that is, if the phenomenon belongs to the class for which the formula was developed. If it does, it strengthens the formula and gives additional assurance that the measurements were correct. If it does not, then it is in order to examine the method employed and, perhaps, once more scan the formula, for it too may be wrong. Sometimes a formula tells an interesting story, but we may fail to listen. It is only recently that such a case has come to light.

When we speak of the laws governing gravitation, we use a formula in which we place the letter *M* as representing the mass of a body. When we speak of the inertia of a body—the quality, or rather, lack of quality, which prevents it from changing the rate or direction of its movement unless a force acts upon it—we also use the letter *M*, and again for the mass of the body. Both formulas are correct. But why should the mass which is a measure of the extent to which a body answers to the force of gravitation be the same as the mass which is a measure of the inertia of the body? In one case this mass is the measure of the rate to which a body is subject to the force of gravitation, in the other case it is the measure of the resistance of a body to changes of its rate of speed or of its direction.

This strange similarity was completely overlooked until a few years ago and now it plays a great rôle in the efforts of scientists to connect the puzzle of gravitation with some other puzzles which have been solved.

Those various sections of the old text-books on physics have come closer and closer together and are overlapping each other more and more. Heat and light are the same as to their nature, and different only as to the number of vibrations. Both are governed by the same laws as electro-magnetic phenomena. Not only the sections of the science of physics, but even the sciences of astronomy and chemistry themselves have been drawn in and made to answer to principles which govern them all.

Science started out with a great variety of materials and forces, but has now arrived at a point where it seems to be almost certain that there is only one material and one force. Perhaps there is no material at all—only energy. We are not yet completely sure because there are still so many things waiting for an explanation in terms of protons, electrons and energy; but every new discovery leads us more and more to the conclusion that we are on the right track. The greatest stumbling block seems to be the universal force of gravitation.

So far, we have not been able to connect this force with anything else. However, it, too, will probably lose some of its mystery before long, for Einstein has succeeded in developing mathematical formulas which show some relation between it and other forces. As yet the connection is in mathematical terms only. We may compare it with the time when light was an electro-magnetic phenomenon only in terms of mathematics, and before Hertz proved it experimentally. How long it will be before we shall see an experimental demonstration that gravitation, too, is merely the expression of already-known forces, is not possible to

say. It may be a hundred years, or it may be to-morrow, or, perhaps, it has been done a few days ago.

We are almost down to bed-rock. We have only protons, electrons and energy. We are almost down to bed-rock, but not quite. Of what is a proton made? A house is built of bricks. The bricks are made of grains of sand. The sand is a compound of silicon and oxygen. Both oxygen and silicon are made up of protons and electrons. The electron is possibly a charge of negative electricity. The proton is possibly a similar charge of positive electricity. But why should a charge of positive electricity weigh 1845 times as much as one of negative electricity? It seems more likely that a proton is something else besides a charge of electricity.

There are many other questions besides the ones indicated in this book which are waiting to be answered. However, when all these are answered, we shall still be asking questions. Our minds will go on asking: what is the cause of this, and what of that? When all the forces and materials shall have been reduced to one single element, we will ask the question: what is this element made of, or what produces this force? There can be no end. We are as little able to settle on a first origin of things as we are to conceive of a beginning or end of time or of space.

If there were no other reason than this—that we cannot expect to reach a final end—it would be enough to show how foolish it is to speak of the war between science and religion. Whether the Creator of this prime force or material or energy be called God or Nature, it is a confession that we are confronted with the unfathomable. Science is aware of it and does not seek to find this Creator. It merely seeks to simplify the relations existing between the millions of seemingly unrelated things. It is succeeding along these lines. But there is no end.

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